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Noise in America: The Extent of the Noise Problem

Bolt Beranek and Newman, Inc.
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16. ABSTRACT

The number of Americans exposed to various levels of occupational and environmental noise is estimated. Estimates are made for 11 categories of noise producers (e.g., traffic, aircraft, construction) using the Ldn or Leq(24) metrics. The assumptions in the models used, including demographic projections, are made explicit for all estimates. Estimates for combined exposures to traffic and other community noise sources are also made, as well as indoor noise exposures from home equipment like fans and clothes washers. According to the estimates, 1.5 million people are exposed to outdoor noise levels (from all sources) of over 75 Ldn, and over 90 million, to levels over 58 Ldn. Over 9 million people are exposed to occupational noise in excess of 80 dB (Leq(24)).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Traffic Noise, Ambient Noise Occupational Noise, Home Applicance Noise Aircraft Noise, Construction Noise, Agricultural Noise, Mechanical Equipment Noise, Noise Exposure, Community Noise Exposure, Recreational Noise. Environmental Noise. Noise Control Noise Pollution		

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1. INTRODUCTION

How much noise is there in America? Previous EPA documents (such as the Title IV report [1]*, its several backup technical documents [2,3,4], and the "Levels Document" [5]) have addressed this question in varying degrees. In this report existing information has been used, other information has been updated, and the range of noise producers has been broadened, in an attempt to define the extent of the noise problem in America even more comprehensively.

By virtue of the Noise Control Act of 1972 [6], the EPA was given a leadership role in assessing and controlling the noise in this country. Under this authority, EPA has published a national strategy of noise control [7], which includes goals for a national program of noise control and various elements of such a program. The general goal of the national noise control effort, taken directly from the Noise Control Act, is "to promote an environment for all Americans free from noise that jeopardizes their health or welfare." Among the elements of this national program are the control of major noise sources (through Federal regulations, State and local control, labeling, and enforcement activities), study of health and welfare effects, and dissemination of information to the public on noise levels and their effects.

A definition of the present extent of the noise problem in America, in total as well as for individual noise producers, is crucial in designing a program to control noise sources in terms of establishing both relative priorities and the amount of noise control necessary. The purpose of this report, then, is to provide information in support of these noise control activities. Specifically, this report attempts to define the number of Americans exposed to different levels of noise, and the sources of noise to which they are exposed.

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*References are listed on Page 17.

2. CATEGORIES OF NOISE PRODUCERS

Noise is a ubiquitous by-product of our modern mechanized society. Since it is difficult to find a device that does not produce noise, the number of noise producers in this country is gigantic. To quantify the extent of the noise problem, the noise producers are divided in this report into 11 categories, based primarily on the situations in which the noise producers occur. Within a given category, therefore, various devices generally have similar noise-generating properties and operational characteristics.

Table 1 lists the noise categories on which this report concentrates (one in each Appendix).

Where does noise affect people? As shown in Table 1, the categories of noise producers described in this report include four primary scenarios of exposure in:

- The community
- Buildings
- The workplace
- Transportation/recreational devices.

TABLE 1. **NOISE SOURCE CATEGORIES INCLUDED IN THIS REPORT.**

Category	See Appendix
Traffic Noise Exposure in the Community	C
Aircraft Noise Exposure in the Community	D
Construction Noise Exposure in the Community	E
Rail Noise Exposure in the Community	F
Industrial Noise Exposure in the Community	G
Agricultural Noise Exposure in the Community	H
Building Mechanical Equipment Noise Exposure in the Community and in Buildings	I
Home Appliances, Power Shop Tools, and Garden Equipment Noise Exposure in the Community and in Buildings, and Exposure of Operators	J
Occupational Noise Exposure	K
Transportation Noise Exposure of Operators and Passengers	L
Recreational Noise Exposure of Operators and Passengers	M

3. EVALUATING NOISE EXPOSURE AND NOISE IMPACT

The extent of the noise produced by a particular device or source has many dimensions: the intensity, or loudness, of the noise at a particular point, as described by its "noise level"; the time characteristics of the noise in terms of its duration, the time of day it occurs, and whether it is a continuous or intermittent sound; the spread of the noise over a geographic area; and the number of people exposed to the particular noise. These aspects considered together constitute the noise exposure. As shown in Fig. 1, the noise exposure nationwide for a particular noise source, that is, a noise producer, is based upon:

- The emission levels and operating characteristics of the source
- The characteristics of the transmission path between the source and the people who hear the source noise
- The distribution of people relative to the source.

For the purpose of defining noise exposure in indoor and outdoor environments at specific locations, the EPA has adopted the yearly day-night sound level, L_{dn} [5]. Appendix A describes this measure of noise exposure (and others) in detail. (A glossary of noise descriptors and other acoustic terms is provided in Appendix B.)

To describe the noise exposure of individuals to levels of noise that might result in hearing loss, the EPA has adopted the 24-hour equivalent sound level, $L_{eq}(24)$[5]. This measure is the equivalent sound level (see Appendix A for a

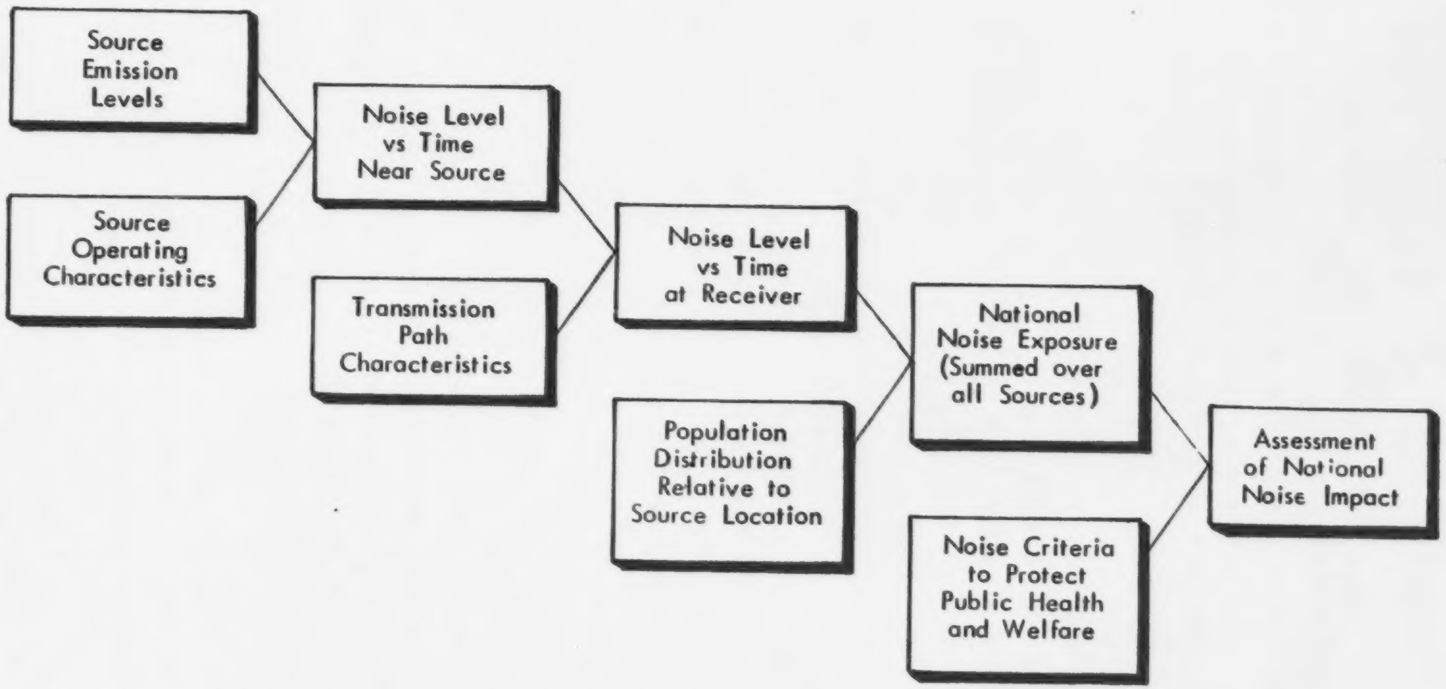
Source Emission Levels
Source Operating Characteristics
Noise Level vs Time Near Source
Transmission Path Characteristics
Noise Level vs Time at Receiver
Population Distribution Relative to Source Location
National Noise Exposure (Summed over all Sources)
Noise Criteria to Protect Public Health and Welfare
Assessment of National Noise Impact

FIG. 1. FACTORS INVOLVED IN ASSESSING NOISE IMPACT.

description) averaged over a full 24-hour day. [When the noise exposure from sources other than workplace noise sources throughout the day is low enough to result in a negligible contribution to the 24-hour average, the $L_{eq}(24)$ is simply 5 dB higher in level than the 8-hour workplace equivalent sound level, $L_{eq}(8)$.]

The pervasiveness of the noise exposure from a particular noise source is described in terms of the number of people exposed to various levels of L_{dn} or $L_{eq}(24)$, depending upon the exposure scenario. The intensity and time characteristics of the noise and the effects of the transmission path characteristics are incorporated in the noise measure [either L_{dn} or $L_{eq}(24)$]; the geographic distribution of the noise source and the people it affects are reflected in the numbers of people exposed to the various levels. Thus, the distribution of people as a function of the noise level provides a very complete description of the extent of noise problems in America.

However, this description of the noise exposure says nothing about the effects of the noise on the people exposed. In order to evaluate such effects to determine if the noise exposure is creating an impact on a certain segment of the population, the noise exposure must be compared with criteria that have been developed for the various effects, following the steps shown in Fig. 1.

In the Levels Document [5], EPA has identified an L_{dn} value of 55 dB outdoors as the level below which the public health and welfare would be protected with an adequate margin of safety in residential areas. Similarly, an L_{dn} value of 45 dB indoors is the level identified for an acceptable living space. In order to protect against hearing loss, an $L_{eq}(24)$ of 70 dB is the level identified (corresponding to an $L_{eq}(8)$ of 75 dB, when the 8-hour noise exposure dominates the 24-hour exposure). When these identified levels are exceeded, a noise "impact" is assumed to occur.

In summary, the extent of noise in America is described in this report as the number of people nationwide exposed to various noise levels for individual categories of noise sources. Therefore, evaluating the noise impact with regard to individual noise effects or for different noise scenarios involves assessment of the number of people at each level of exposure above an appropriate criterion level.

4. DEVELOPMENT OF ESTIMATES OF THE EXTENT OF NOISE EXPOSURE

As described earlier, eleven categories of noise sources have been defined for the purpose of estimating the nationwide extent of noise exposure. Table 1 lists these categories and the appendices that are devoted to these sources. Each appendix includes, where appropriate, a description of the noise model used to develop the exposure estimates, data on source noise emissions and operating characteristics, transmission path characteristics, population distribution information, and the resulting exposure estimates.

Certain noise source categories have been omitted or are incomplete. They include the noise of commercial establishments, such as automobile repair shops, and the occupational noise exposure of some industries for which data are lacking. Similarly, the noise of people and animals has not been included (although on the local level, these are often the most common causes of noise complaints).

The noise producers covered in this report are mechanical devices. Throughout America, however, an "ambient" or background sound level caused by natural phenomena (rain, wind, insects, etc.) also occurs. Most ambient noise levels range from 35-55 dB [3] as reported in surveys. Very little data exist which can produce estimates of any scientific significance. Ambient noise is believed to have a minimal impact on the population.

The noise exposure estimates contained in this report are based on the latest information available at present (1980), although for a number of sources the nonacoustic data used to make the estimates (number of items in use nationwide, number of people living in different areas of the country, etc.) are derived from data from earlier years (typically 1975 and beyond).

5. SUMMARY OF NOISE EXPOSURE ESTIMATES

Appendices C through M provide estimates of the nationwide noise exposure [in terms of the distribution of population exposed to various levels of L_{dn} or $L_{eq}(24)$]. The estimates for each noise category were developed on the basis of analytical models that take into account characteristics of both the noise source and the communities exposed. Models of varying complexity are used to represent real life in such a way that the estimates can be obtained in quantitative terms.

As Fig. 1 shows, each of the models uses the emission levels and operating characteristics of the noise sources in each particular noise category, transmission path characteristics, and population distribution information.

To make the noise exposure estimates, existing noise sources and community data have been used. Generally, the noise source levels are based upon levels reported in the literature. In a few cases, however, little data are available for a particular source. Data on operating characteristics and population distributions relative to numbers of sources have been harder to find, and in these cases, assumptions have been made to produce the estimates. Wherever possible, the sources of the data are documented; assumptions used in the analyses are labeled as such.

As a summary, Table 2 shows the estimated distribution of the U.S. population as a function of L_{dn} value for the major noise categories examined. The L_{dn} values refer to community (residential) outdoor noise exposure (note that the construction estimates include nonresidential outdoor exposure). Similarly, Table 3 summarizes noise exposure estimates for major indoor noise sources. Finally, Table 4 summarizes the occupational and nonoccupational noise exposure with regard to risk of noise-induced hearing loss.

Concerning the information presented in these tables, it should be emphasized that the underlying data are of varying quality. For the traffic, aircraft, railway, and construction noise source categories, the estimates are based on extensive research and measurement studies. For many of the remaining categories, the estimates are based on limited data and/or simplistic models.

6. EXPOSURE TO MULTIPLE SOURCES

As is often typical, a worker incurring a given noise exposure from his workplace may also experience additional high noise exposure as he commutes to work or joins in recreational activities. Unfortunately, there are no data available relating

TABLE 2. SUMMARY OF U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn}* OR HIGHER FROM NOISE SOURCES IN THE COMMUNITY.†

L_{dn}	Number (in Millions) of People for Each Noise Category**				
(dB)	Traffic	Aircraft	Construction††	Rail	Industrial
>80	0.1	0.1	—	—	—
>75	1.1	0.3	0.1	—	—
>70	5.7	1.3	0.6	0.8	—
>65	19.3	4.7	2.1	2.5	0.3
>60	46.6	11.5	7.7	3.5	1.9
>55	96.8	24.3	27.5	6.0	6.9

---

* L_{dn} levels are yearly averages, outdoors.

† Note that there is some overlay among populations exposed to different noise sources, i.e., some of the 96.8 million people exposed to traffic L_{dn} levels of 55 dB and above are also exposed to aircraft levels (see Sec. 6 for estimates of this overlap).

** See the following appendices for references to individual noise categories:

Noise Category	Appendix
Traffic	C
Aircraft	D
Construction	E
Rail	F
Industrial	G

††Construction estimates include both residential and nonresidential exposure.

TABLE 3. SUMMARY OF U.S. POPULATION EXPOSED TO L_{dn} LEVELS* OF 45 dB OR HIGHER FROM NOISE SOURCES INDOORS.

Noise Source	Number (in Millions) of People Exposed to L_{dn} Levels at or above 45 dB†
Clothes Dryer	42.3
Clothes Washer	52.6
Dehumidifier	39.4
Dishwasher	35.0
Refrigerator	68.6
Room Air Conditioner	78.9
Fan	118.3
Humidifier	46.0

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*L_{dn} levels are yearly averages, indoors.

†From Appendix J.

TABLE 4. SUMMARY OF U.S. POPULATION EXPOSED TO $L_{eq}(24)$ LEVELS* OF 70 dB AND 80 dB OR HIGHER FROM OCCUPATIONAL AND NONOCCUPATIONAL NOISE SOURCES.

	Number (in millions) of People Exposed to $L_{eq}(24)$ Levels at or above 70 and 80 dB	
Noise Exposure Scenario	70 dB	80 dB
Occupational† (Appendix K)		
Agriculture	NA**	0.3
Mining	NA	0.4
Construction	NA	0.5
Manufacturing/Utility	NA	5.1
Transportation	NA	1.9
Military (DOD)	NA	1.0
Total Occupational	NA	9.2
Nonoccupational		
Transportation Operators/ Passengers (Appendix L)		
Aircraft	0.4	
Motorcycles	5.2	5.2
Buses	10.4	
Rapid Transit	2.0	
Recreational Operators/ Passengers (Appendix M)		
Snowmobiles	1.7	1.7
Motorcycles (off-road)	2.6	2.6
Motorboats	2.3	
Auto Racing	0.1	0.1
Consumer Products (Appendix J)		
Power Shop Tools	30.7	
Outdoor Power Equipment	11.0	6.6
Total Nonoccupational	66.4††	16.2††

---

* $L_{eq}(24)$ levels are yearly averages.

† Occupational exposure estimates for $L_{eq}(24)$ levels of 70 dB are unavailable.

**NA denotes not available.

††This total may include some people counted twice because of overlap. A total of occupational and nonoccupational exposure is not included because of the probability of additional overlap between the two populations.

numbers of industrial workers to the use of transportation or recreational devices. One could, however, for different hypothetical exposure profiles, determine the total exposure of a person.

With regard to outdoor community exposure, the situation is somewhat different. Most people are generally subjected to the noise of more than one of the noise categories. In order to account for this multiple exposure, it is helpful to note the manner in which traffic noise, the most dominant noise source, is distributed throughout the entire population of approximately 200 million people.* It is not unreasonable to assume that the exposure of another noise source, like aircraft, might be distributed across this population in a manner similar to that of traffic noise. Similarly, construction†, rail, and industrial noise exposure could independently be distributed throughout this population, in a manner corresponding to the traffic distribution. This traffic noise exposure distribution is as follows (from Table 2):

L_{dn} Range (dB)	Number of People (Millions)	Percentage of Total Population
>80	0.1	0.05
75-80	1.0	0.5
70-75	4.6	2.3
65-70	13.6	6.8
60-65	27.3	13.7
55-60	50.2	25.1
<55	103.2	51.5

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*This population figure represents the approximate 1980 urban and rural population, excluding the rural farm population.

†Only residential construction noise exposure can be distributed in this manner.

That is, 25.1% of the 200 million (non-farm) population in the United States are exposed to traffic noise levels in the range of 55 to 60 dB, 13.7% are exposed to traffic noise levels in the range of 60 to 65 dB, etc.

Accordingly, the 12.8 million people exposed to aircraft levels of 55 to 60 dB could be similarly distributed so that 25.1% (3.2 million) are also exposed to traffic levels of 55 to 60 dB, and 13.7% (1.8 million) are also exposed to traffic levels of 60 to 65 dB, etc. For these people, the combined exposure will result in a higher total level than either the aircraft or traffic exposure alone had indicated. In this way, the distribution of people exposed to aircraft and traffic noise, construction and traffic noise, rail and traffic noise, and industrial and traffic noise can be determined.

The distribution of people who are exposed to traffic but not aircraft, construction, rail, and industrial noise can then also be determined. For example, there are 43.2 million people with residential exposure greater than 55 dB due to aircraft (24.3 million), construction (6.0 million, see Appendix E), rail (6.0 million) and industrial (6.9 million) noise sources. Of these, 13.7% or 5.9 million will also be exposed to traffic noise levels of 60 to 65 dB. Since there is a total population of 27.3 million exposed to traffic noise levels of 60 to 65 dB, 21.4 million will be exposed to traffic alone in this range. Then the traffic alone, traffic plus aircraft, traffic plus construction, traffic plus rail, and traffic plus industrial distributions can be combined together. The individual and combined distributions are shown in Table 5.

It is likely that there are some locations (and therefore, some people) exposed to the noise of more than two sources (e.g.,

TABLE 5. U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn}* OR HIGHER FOR COMBINED EXPOSURES TO TRAFFIC AND OTHER NOISE SOURCES IN THE COMMUNITY.

	Number (in Millions) of People					
Ldn† (dB)	Traffic Only	Traffic and Aircraft	Traffic and Construction**	Traffic and Rail	Traffic and Industrial	Total
>80	0.1	0.1				0.2
>75	0.9	0.5		0.1		1.5
>70	4.5	2.2	0.2	1.0	0.2	8.1
>65	15.2	7.6	0.8	3.0	1.2	27.8
>60	36.6	16.1	2.8	4.4	3.7	63.6
>58	49.2	24.3	6.0	6.0	6.9	92.4

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*L_{dn} levels are yearly averages, outdoors..

†The distribution starts at 58 dB since the analysis involves combining distributions of population at 55 dB and above.

**Includes only residential exposure to construction noise.

traffic, aircraft and rail). However, the distribution of people exposed to two non-traffic sources, as well as to traffic noise, is unknown and difficult to estimate. Since the total number of people exposed individually to construction, rail and industrial noise above an L_{dn} value of 55 dB is small (less than 7 million each), it is reasonable to expect that the population distribution for various L_{dn} values for multiple sources would be quite small as well. Thus, to a first approximation, the "total" distribution shown in Table 5 represents the distribution of the U.S. population as a function of L_{dn} level for combined exposure to all outdoor noise sources.

REFERENCES

1. Administrator of the EPA, "Report to the President and Congress on Noise," in compliance with Title IV of Public Law 91-604, the Clean Air Act Amendments of 1970, Senate Document 92-63, U.S. Government Printing Office, February 1972.

2. EPA Technical Information Document NTID300.1, "Noise from Construction Equipment and Operations, Building Equipment and Home Appliances," (EPA Contract 68-04-0047, Bolt Beranek and Newman Inc.).

3. EPA Technical Information Document NTID300.3, "Community Noise," (EPA Contract 63-04-0046, Wyle Laboratories).

4. EPA Technical Information Document NTID300.13, "Transportation Noise and Noise from Equipment Powered by Internal Combustion Engines," (EPA Contract 68-04-0046, Wyle Laboratories).

5. Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect Health and Welfare with an Adequate Margin of Safety," EPA Report No. 500/9-74-004, March 1974.

6. The Noise Control Act of 1972, PL 92-574.

7. Environmental Protection Agency, "Toward a National Strategy for Noise Control," April 1977.

APPENDIX A. DESCRIPTION AND MEASUREMENT OF SOUND

The nature of sound is often debated with the following question: if a tree falls in the forest, and no one is near to hear it fall, is there a sound? In other words, does sound deal with a cause (a vibrating object such as the falling tree) or with an effect (the sensory experience of hearing)? The answer is that sound is both these things. It is both a physical event and a physiological sensation.

The sensation of sound is a result of oscillations in pressure, particle displacement, and particle velocity, in an elastic medium between the sound source and the ear. Sound is caused when an object is set into vibration by a force. This vibration causes molecular movement of the medium in which the object is situated, thereby propagating a sound wave. Sound is heard when a sound wave impinges on the human ear and is recognized by the brain. Further, the characteristics of the sound wave must fall within the limitations of the human ear for the sound to be heard because the human ear cannot hear all sounds. Sound frequencies (pressure variation rates) can be too high (ultrasonic) or too low (infrasonic), or the sound amplitudes may be too soft to be heard by humans.

A.1 Sound Propagation

Sound is transmitted from the sound source to the air by the movement of molecules in the medium. This molecular movement is called a sound wave.

In air, sound waves are described in terms of propagated changes in pressure that alternate above and below atmospheric pressure. These pressure changes are produced when a vibrating sound source actually "bumps" into the adjacent air molecules forcing them to move. These molecules, in turn, bump into others farther away from the source, and so on. Thus, the energy from the sound source is imparted to the air molecules and thereby is transmitted through the medium. An analagous situation occurs when dropping a pebble into a still pond. When the pebble hits the water, waves on the surface emanate from the point of impact in all directions, moving outward in concentric spheres, while individual water molecules merely oscillate up and down in one place.

There are two phases to a sound wave: compression and rarefaction. The compression phase occurs when the air molecules are forced close together (causing an instantaneous increase in air pressure), and the rarefaction phase occurs when the air molecules are pulled apart from each other (causing an instantaneous decrease in atmospheric pressure). The complete sequence of one compression and one rarefaction is called a cycle. The cycle of a sound wave and its component parts are illustrated in Fig. A.1.

A.2 Perception of Sound

The human ability to perceive a specific sound depends upon its magnitude and character, as differentiated from the magnitude and character of all the other sounds in the environment.

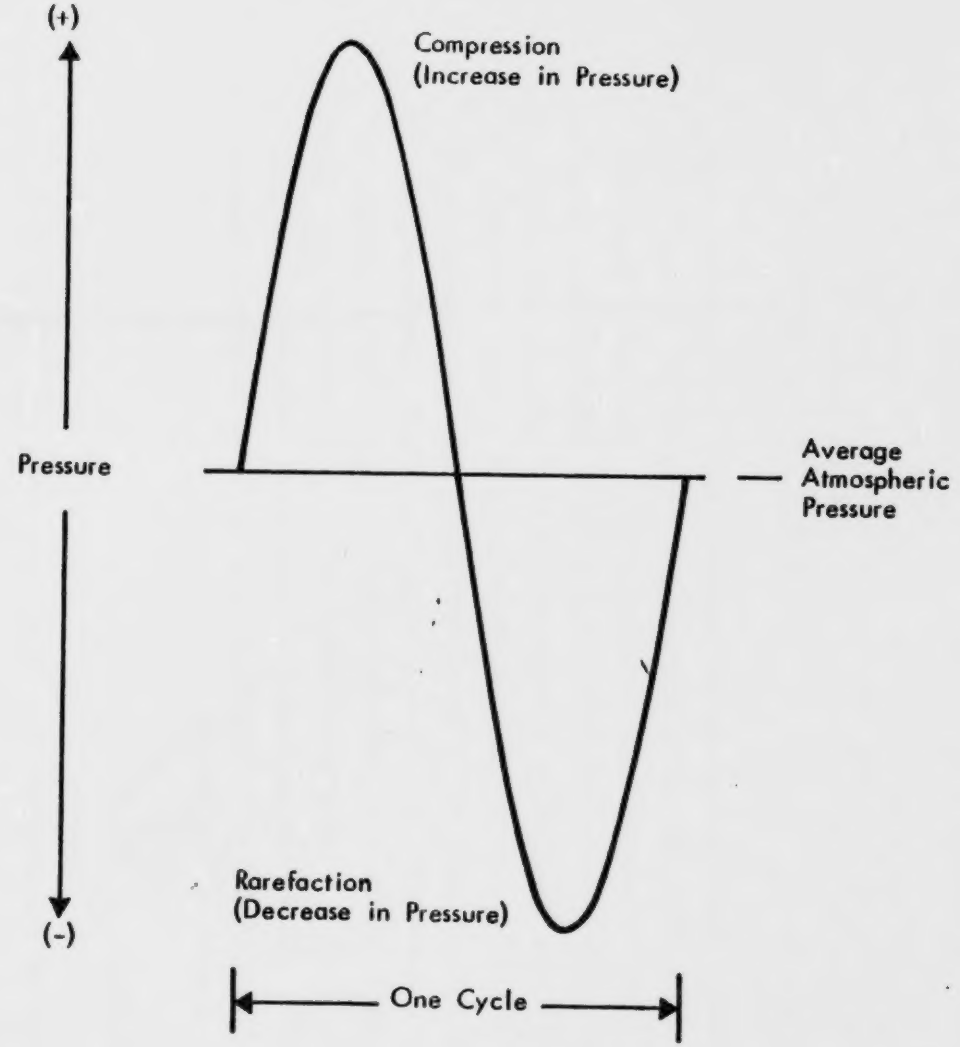

(+)
Pressure
(-)
Compression
(Increase in Pressure)
Average
Atmospheric
Pressure
Rarefaction
(Decrease in Pressure)
One Cycle

FIG. A.1. CYCLE OF A SOUND WAVE AND ITS COMPONENT PARTS.

A number of qualitative descriptions may be used to describe a sound, such as:

- Magnitude - loud or faint
- Broadband frequency content - high-pitched hiss or low rumble
- Discrete frequency content - tonal or broadband
- Intermixing of pure tones - harsh or melodic
- Time variation - intermittent, fluctuating steady or impulsive
- Duration - long or short.

Conventional measures of sound attempt to determine its magnitude with respect to human perception, trying to account for the frequency response characteristics of the ear. Most measures do not account for other subjective attributes. Such attributes are difficult to measure individually, and it is even more difficult to combine them into a single measure. However, one or more of these attributes may be important in enabling a human to perceive a specific sound; for example, an intermittent impulsive "rat-tat-tat" is more easily distinguishable than a steady broadband sound. To account for these attributes, which are not easily measured, some noise rating scales have fixed penalties that are applied to the measured level to increase its value.

A.3 Magnitude of Sound

The unit used to measure the magnitude of sound level is the decibel. In the phrase, "The sound level is so many decibels" its use is analogous to the use of "inch" in the phrase, "The length is so many inches" or to "degree" in the phrase, "The temperature on the Celsius scale is so many degrees". However, unlike the scales of length and temperature, which are linear scales, the sound level scale is logarithmic. For measurement of sound pressure, sound pressure level (SPL) is defined as 10 times the logarithm to the base 10 of the ratio of the measured mean square sound pressure (P) to the square of a specified reference sound pressure (P_r):

$$SPL = 10 \log (P/P_r)^2, \text{dB.} \qquad (A.1)$$

By definition, therefore, a sound that has 10 times the energy of the reference sound is 10 decibels (dB) greater, and one that has 100 times the energy (or 10 x 10 times) of the reference sound is 20 dB greater (10 + 10 dB).

The ear is sensitive to a wide range of sound levels, and this creates many difficulties in working with absolute sound pressure units. For instance, the human ear is sensitive to a pressure range greater than 0.00002 to 20,000 newtons per sq meter. Because of the awkwardness and difficulty of working with such a broad range of absolute units, the decibel has been adopted to compress this large range and more closely follow the response of the human ear.

The use of the logarithmic decibel scale requires somewhat different arithmetic than we are accustomed to using with linear scales. For example, consider two similar but independent noise sources operating simultaneously, and each producing an average sound pressure P. The sound energy (square of the sound pressure) generated by the two sources will add together to give sound energy twice that which would result from either source operating alone.

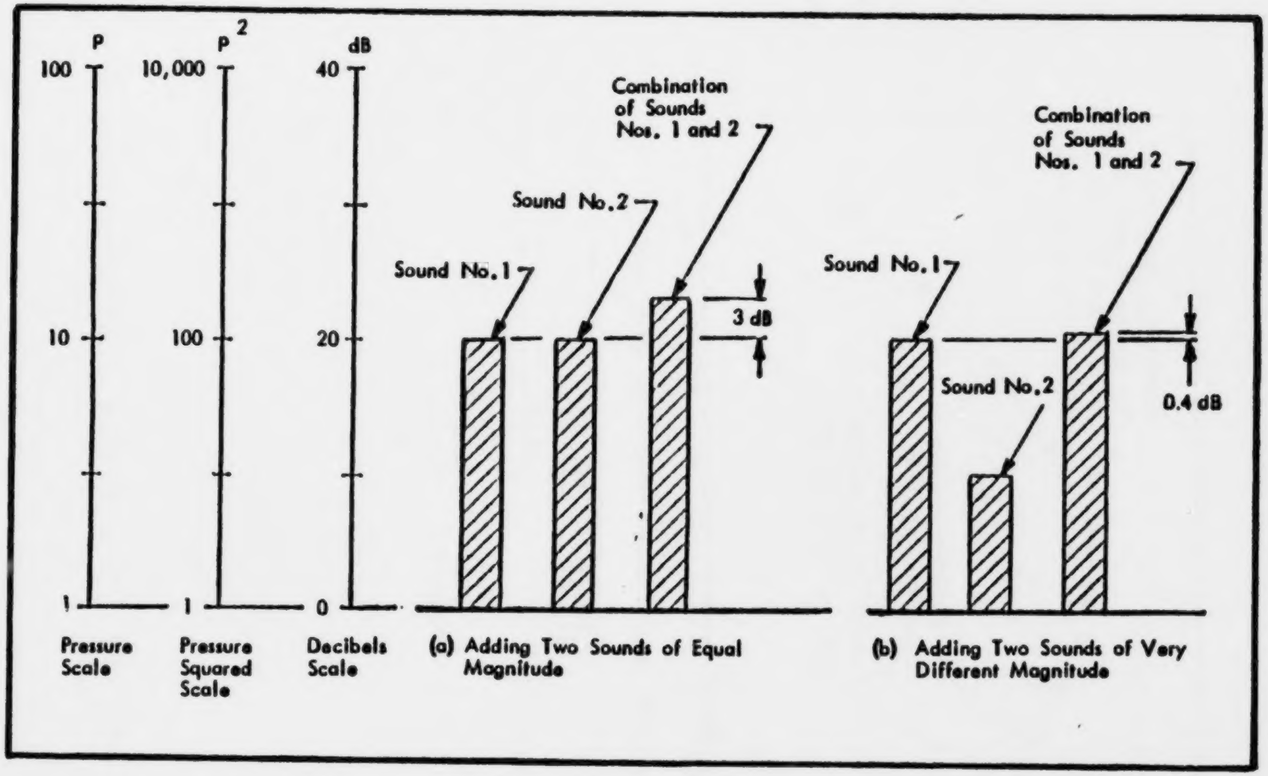
However, the resulting sound pressure level (SPL') in dB from the combined sources will be only 3 dB higher than the level produced by either source alone, since the logarithm of 2 is 0.3 and 10 times 0.3 is 3. This solution can be shown mathematically as follows:

$$SPL' = 10 \log (P + P) / Pr = 10 \log 2 P / Pr$$

$$= 10 \log 2 + 10 \log P / Pr = 3 + SPL. \qquad (A.2)$$

If we have two sounds of different magnitude from independent sources, then the level of the sum will always be less than 3 dB above the level produced by the greater source alone. If the two sound sources produce individual levels that are different by 10 dB or more, then adding the two together produces a level that is not significantly different from that produced by the greater source operating alone, as illustrated in Fig. A.2.

Two sounds that have the same sound pressure level may "sound" quite different (i.e., a rumble vs a hiss) because of differing distributions of sound energy in the audible frequency range. The distribution of sound energy as a function of frequency is termed the "frequency spectrum" (see Fig. A.3 for an example). The spectrum is important to the measurement of the magnitude of sounds because the human ear is more sensitive to sounds at some frequencies than at others. For example, the human ear hears better in the frequency range of 1,000 to 10,000 cycles per second (or Hertz) than at very much lower or higher frequencies. Therefore, in order to determine the magnitude of a sound on a scale that is proportional to the magnitude as perceived by a human, it is necessary to weight that part of



(a) Adding Two Sounds of Equal Magnitude

(b) Adding Two Sounds of Very Different Magnitude

FIG. A.2. EXAMPLE OF THE CHANGE ON THE DECIBEL SCALE RESULTING FROM ADDING THE ENERGIES OF TWO SOUNDS TOGETHER.

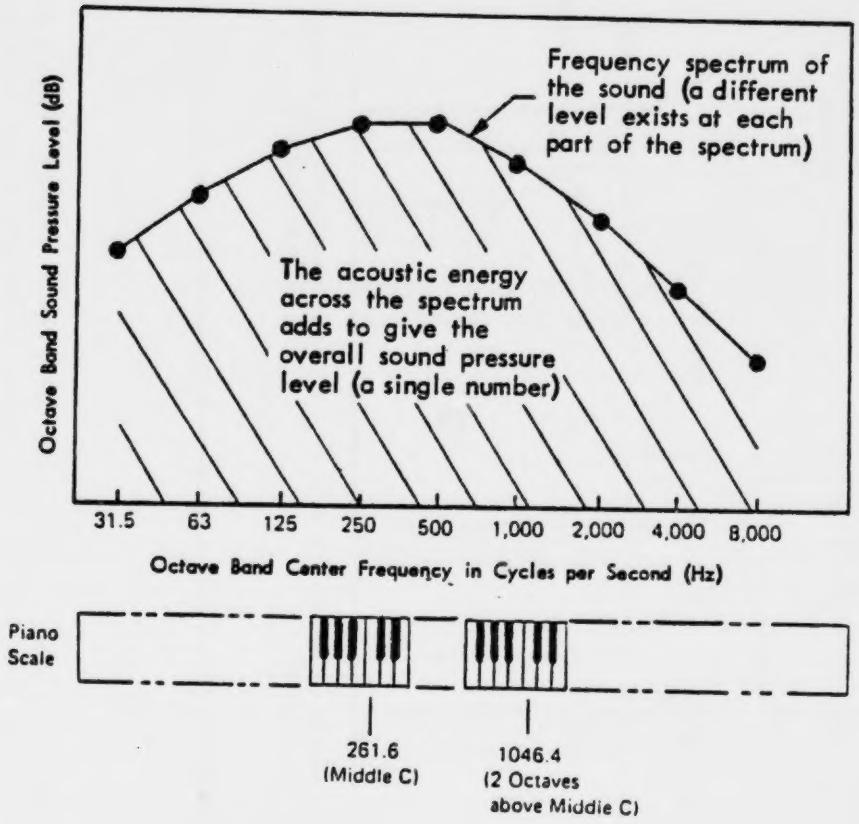


FIG. A.3. EXAMPLE OF A FREQUENCY SPECTRUM OF A SOUND.

the sound energy spectrum humans hear most easily; that is, count it more heavily when adding up the total sound energy as perceived. Figure A.4 illustrates this concept of weighting the physical sound energy spectrum to account for the frequency response of the ear.

A.4 Frequency Weighting

Scientists who work in acoustics have attempted for many years to find the ideal method to weight the frequency spectrum of sound to match accurately the perception of sound by the human ear. These attempts have produced many different scales of sound measurement, including A-weighted sound level (and also B, C, D, and E-weighted sound levels), perceived noise level, and loudness. A-weighting, which was developed in the 1930s for use in a sound level meter, accomplishes the weighting by an electrical network that works in manner similar to the bass and treble controls on a hi-fi set.

A-weighting has been used extensively throughout the world to measure the magnitudes of sounds of all types. Because of its universality, it was adopted by the EPA and other government agencies for the description of sounds in the environment. A newer weighting, such as D or E, based on the decade of research leading to the perceived noise level scale, might eventually supplant A-weighting as the universal method. But until one of these newer scales is in common use and its superiority over A-weighting for measurement of environmental sounds is demonstrated, A-weighting is expected to dominate.

The zero value on the A-weighted sound level scale (sound level, for short) is the reference pressure of 20 micronewtons

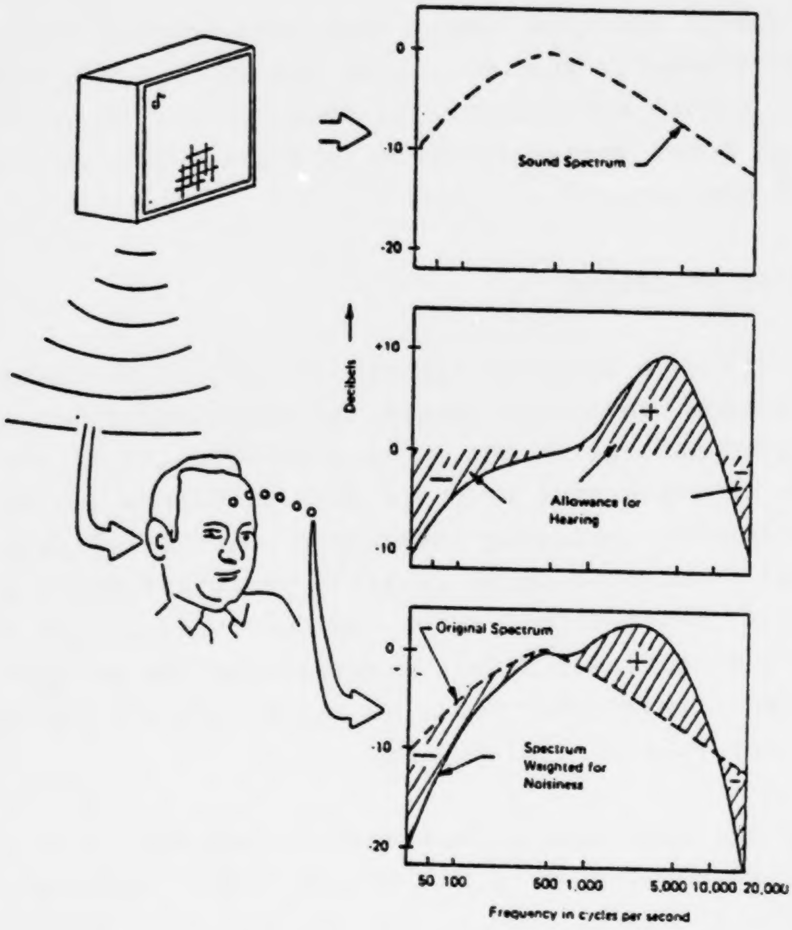


FIG. A.4. WEIGHTING THE MEASURED SPECTRUM TO ACCOUNT FOR THE FREQUENCY RESPONSE TO THE HUMAN EAR.

per square meter ($\mu N/M^2$). This value was selected because it approximates the smallest sound pressure that can be detected by a human. The average A-weighted sound level of a whisper at a 1-meter distance from the person who is whispering is 40 dB; the sound level of a normal voice speaking 1 meter away is 57 dB; a shout, 1 meter away, is 85 dB.

A.5 Time Variation of Sound

Generally, the magnitude of sound in the environment varies in a random fashion with time. There are many exceptions; for example, the sound level of a waterfall is relatively constant with time, and the sound level of a room air conditioner is periodically high and low, depending on whether it is on or off. But in most places the outdoor sound is ever-changing in magnitude, because it is influenced by sounds from many sources--people, animals, many types of vehicles, near and far. Figure A.5 illustrates how the sound level of different types of sounds vary over time.

In one sense, the variation of sound levels with time is analogous to the variation in shade (light to dark) in a picture or one's surroundings. Similarly, the changing characteristics of the subjective attributes and frequency spectrum to the ear might be analogous to change in color to the eye. It may be that the changes in magnitude and character of the sound in the environment with time add richness to the human environmental experience, as do visual changes in intensity and color. Certainly the varying sounds of bird songs and rustling leaves in the forest are more rewarding than the utter silence that precedes a storm or the steady hum of a noisy ballast transformer in a fluorescent light. Changing patterns of sound serve to

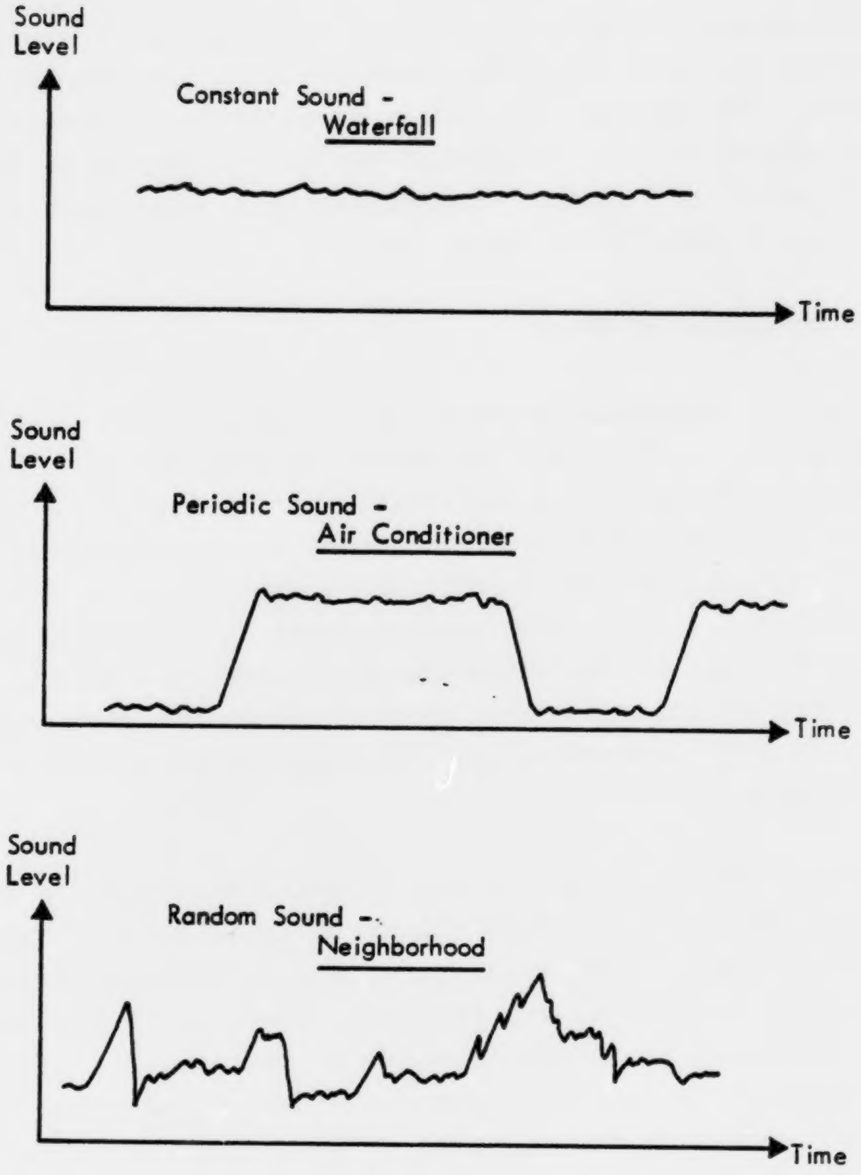


FIG. A.5. EXAMPLES OF SOUND LEVEL VARIATION OVER TIME.

make us continually aware of life going on around us and seem to provide assurance that all is well. However, if the fluctuation in magnitude of sound exceeds the range that is acceptable in a specific context, if the average sound level is high enough to interfere with verbal communication, job performance, or some other activity, or if a sound of unusual character or undesirable connotation is heard, the subconscious feeling of well-being may be replaced with feelings of adversiveness and annoyance.

It is easy to measure the continuously changing magnitude of the sound level. It may be displayed on a graphic level recorder, in which a pen traces a line on a sheet of moving paper. Fig. A.6 illustrates two 8-min. samples of such a recording. Several features of these two samples should be noted.

The first feature is that the sound level varies with time over a range of 33 dB, which is a ratio of 2000 to 1 in sound energy. Second, in these two samples, the sound appears to be characterized by a fairly steady-state lower level, upon which the increased sound levels associated with discrete (individual) single events are superimposed. This fairly constant lower level is often called the residual sound level. An example of residual sound is the continuous sound one hears in the backyard at night, when no single source can be identified, so the sound seems to come from "all around." The distinct sounds that are superimposed on the residual sound level, such as the aircraft overflight, cars, and dogs barking, can be classified as the result of a succession of single events.

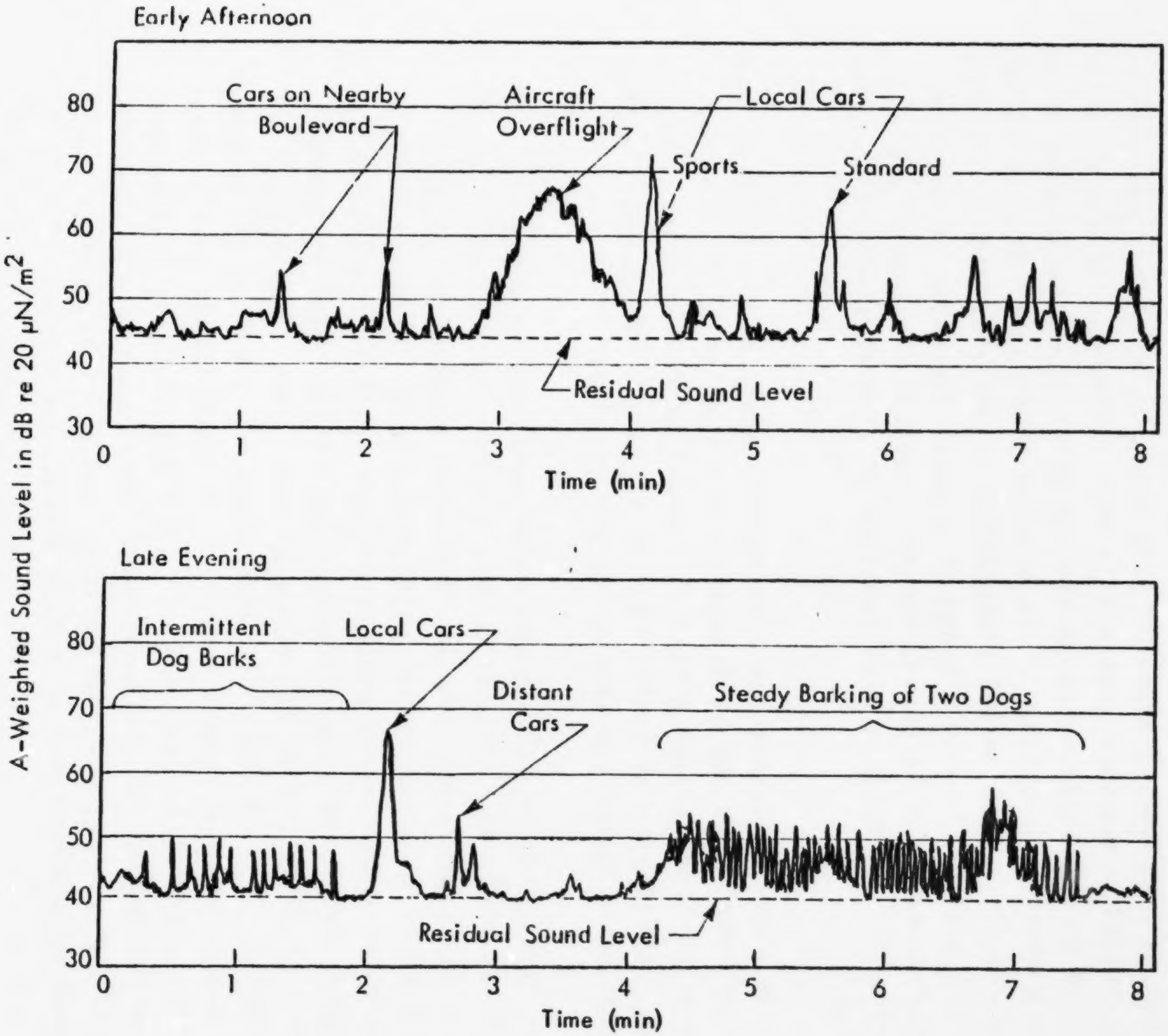


FIG. A.6. TWO SAMPLES OF OUTDOOR SOUND WITH THE MICROPHONE LOCATED 20 FT. FROM STREET CURB ON A QUIET STREET IN PACIFIC PALISADES, CA.

Each single event may be partially characterized by its maximum level. It may also be characterized by its time pattern. The sound level of the aircraft in the example is above that of the residual sound level for approximately 80 sec, whereas the sound levels from the cars passing by on the street are above the residual sound level for much shorter durations, ranging between about 5 and 20 sec. Clearly, if the sound associated with these single events were of sufficient magnitude to intrude on an individual's activities--conversation, thinking, watching television, etc.--the duration factor might be expected to affect his degree of annoyance. Similarly, it might be anticipated that the number of times such an event recurred also would affect his degree of annoyance.

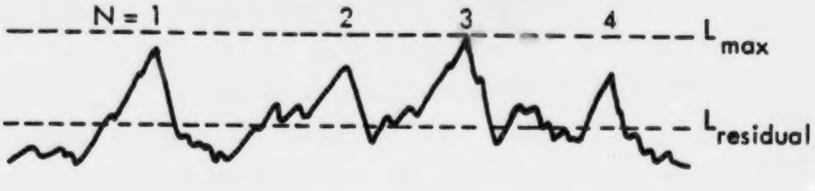
The data from these continuous recordings of sound are very instructive in providing an understanding of the nature of the outdoor sound environment at any neighborhood location. However, in order to quantify an outdoor sound environment at one location so that it can be compared with the sound environment at other locations, it is useful to simplify its description by eliminating much of the temporal detail. One way of accomplishing this simplification is to measure the value of the residual sound level and the values of the maximum sound level for specific single event sounds at various times during the day, using either a simple sound level meter or the continuous graphic level recording of its output. Another method of quantifying the sound environment is to determine the statistical properties of the sound level by attaching a statistical analyzer to the output of the sound level meter. This procedure allows one to determine the amount of time that the sound level exceeds any stated sound level, or, conversely, the sound level that is exceeded for a stated percentage of the time. A third method is to determine the value of a steady-state sound that has the same A-weighted sound energy as that contained in the time-varying sound. This value is termed the equivalent sound level. These three methods of deriving single number measures of time-varying noise levels are illustrated in Fig. A.7.

Each of these descriptors has its own special usefulness. Residual and maximum sound levels are easily measured by simple equipment; however, such measurements give no indication of the duration of the various single events, nor a notion of the average "state" of the environment.

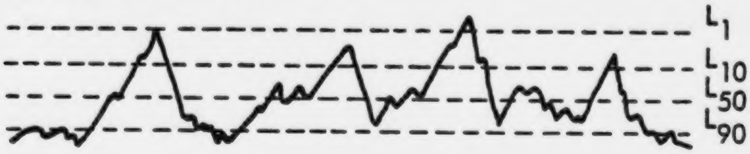
The statistical method is relatively difficult to accomplish with simple equipment. Most monitoring systems designed for the purpose can give the complete detailed statistical distribution curve of sound level vs time for any desired duration: for example, each hour of the day, daytime or nighttime, or a 24-hour day. Such a curve is often a most useful reduction of the detail contained in the graphic level recording, although it eliminates all information about specific events.

The equivalent sound level is also best measured with an instrument or monitoring system designed specifically for this purpose. A single value can be obtained for any desired duration, a value that includes all of the time-varying sound energy in the measurement period. As such, it is a more complete description than a single value of level and time taken from a statistical description. For example, if the "level that is exceeded 10% of the total time" is used as the descriptor of the time-varying sound, its value remains constant and independent of the magnitudes of all higher level sounds as long as their durations are less than 10% of the total time,

(a) Maximum Level and Number of Events

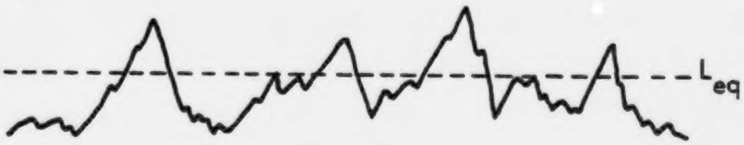


(b) Statistical Levels



L_x = Level Exceeded x Percent of the Time

(c) Equivalent Level



L_{eq} = Energy Equivalent Level

FIG. A.7. THREE MEASURES OF ENVIRONMENTAL NOISE.

whereas the energies associated with these sounds of higher level are fully accounted for in the equivalent sound level.

The major virtue of the equivalent sound level is that its magnitude correlates well with the effects on humans that result from a wide variation in types of environmental sound levels and time patterns. It has been shown to provide good correlation between noise and speech interference and noise and risk of hearing loss. It also is the basis for the measure of the total outdoor noise environment, the day-night sound level, which correlates well with community reaction to noise and to the results of social surveys of annoyance to aircraft noise.

The day-night sound level is defined as the A-weighted equivalent sound level for a 24-hour period with a +10-dB weighting applied to the equivalent sound levels measured during the nighttime hours of 10 p.m. to 7 a.m. The nighttime weighting increases the levels measured during the nighttime by 10 dB. Hence, an environment that has a measured daytime equivalent sound level of 60 dB and a measured nighttime equivalent sound level of 50 dB has a weighted nighttime sound level of 60 dB (50 + 10) and a day-night sound level of 60 dB. Examples of measured day-night sound levels are given in Fig. A.8.

A.6 Characterizing Specific Sounds

The sounds that, combined, make environmental sound can be considered a collection of steady-state sources (such as transformers) and the sounds of time-varying single-event sources which occur at random or regular intervals (such as moving vehicles), superimposed on a quasisteady-state residual or background level of sounds which are indistinguishable.

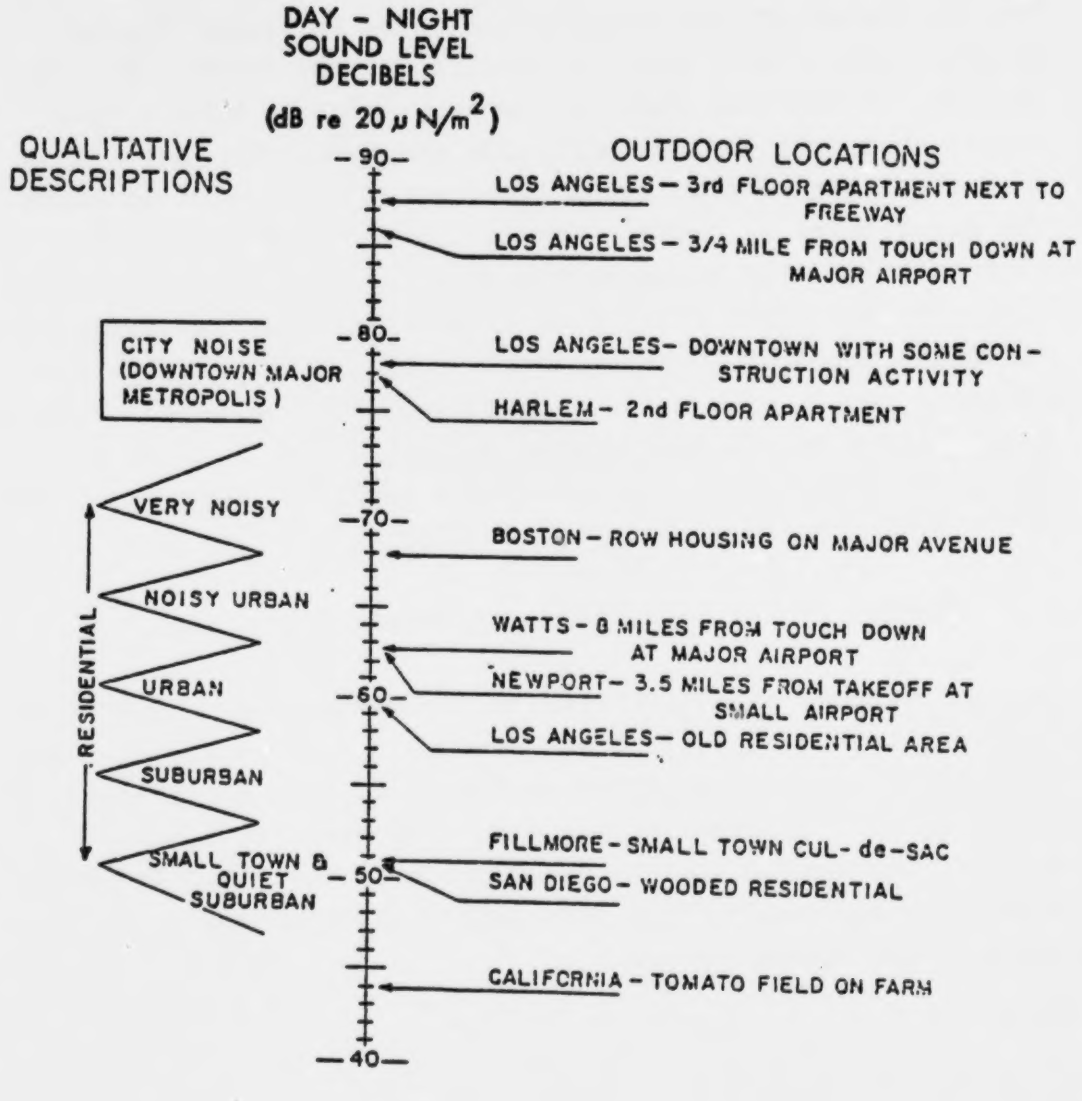


FIG. A.8. EXAMPLES OF OUTDOOR DAY/NIGHT SOUND LEVELS IN dB MEASURED AT VARIOUS LOCATIONS.

The descriptor of the steady-state sound is simply the A-weighted sound level and the duration of the event. The descriptor for the time-varying sounds associated with single events must include both magnitude and duration. One method is to measure the maximum sound level and the duration in which the sound level is above a stated number of decibels below the maximum level: for example, the number of seconds between the time that the sound rises from 10 dB below maximum, to maximum, and falls again to 10 dB below maximum. An alternative description, which produces a single value for the sound of the single event is the sound exposure level, the level of the total sound energy at the microphone resulting from the event. These concepts are illustrated in Fig. A.9.

A.7 Summary of Key Descriptors of Sound

For the purpose of quantifying environmental sound in this discussion, four quantities listed in Table A.1 are useful. All are based on the A-weighting, which accounts approximately for the frequency response of the ear. All have logarithmic scales, all use the decibel (dB) as their unit, and all have the same magnitude of the reference sound pressure of 20 micronewtons per square meter.

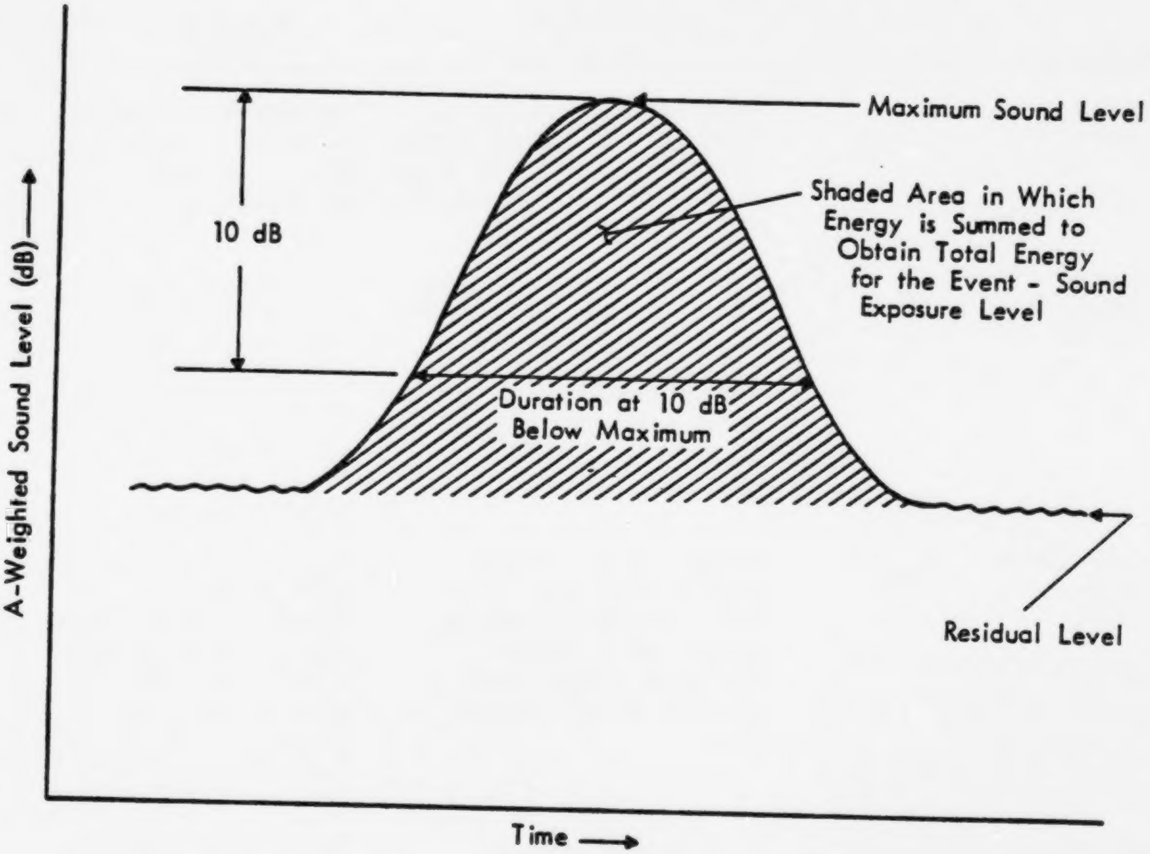

Maximum Sound Level
Shaded Area in Which Energy is Summed to Obtain Total Energy for the Event - Sound Exposure Level
10 dB
Duration at 10 dB Below Maximum
Residual Level
A-Weighted Sound Level (dB) ⟶
Time ⟶

FIG. A.9. DESCRIPTION OF THE SOUND OF A SINGLE EVENT.

TABLE A.1. PRINCIPAL DESCRIPTORS OF ENVIRONMENTAL SOUND.

Quantity	Symbol Abbreviation	Short Description	Principal Uses
Sound Level	L	Mean square value of A-weighted sound pressure level at any time referenced to a reference pressure	Describes magnitude of a sound at a specific position and time
Sound Exposure Level	L_s	Time integral of the mean square A-weighted sound pressure referenced to a mean square reference pressure and 1-sec duration	Describes magnitude of all of the sound at a specific position accumulated during a specific event, or for a stated time interval
Equivalent Sound Level	L_{eq}	Level of a steady sound that has the same sound exposure level as a time-varying sound over stated time interval	Describes average (energy) state of environment; usually employed for durations of 1 hr [L_{eq}(1)], 8 hr [L_{eq}(8)], or 24 hr [L_{eq}(24)]
Day-Night Sound Level	L_{dn}	Equivalent sound level for a 24-hr period with a +10 dB weighting applied to all sounds occurring between 10 p.m. and 7 a.m.	Describes average environment in residential situations; accounting for effect of nighttime noises; often is averaged over a 365-day year

APPENDIX B. GLOSSARY OF NOISE TERMS*

Acoustic Intensity - see Sound Intensity.

Acoustic Power - see Sound Power.

Ambient Noise - Ambient noise is the overall composite of sound in a given environment.

Amplitude - A sound's amplitude can describe the magnitude of sound at a given location away from the source, that is, its sound pressure or sound intensity, or it can refer to the overall ability of the source to emit sound measured by its sound power.

Anechoic Room - An anechoic room has essentially no boundaries to reflect sound energy generated therein. Thus, a sound field generated within an anechoic room is referred to as a free field.

Audiogram - An audiogram is a record of hearing threshold levels as a function of frequency. The threshold levels are referenced to statistically normal hearing threshold levels.

Audiometer - An audiometer is an instrument for measuring hearing sensitivity.

Critical Band - A critical band is a frequency bandwidth characteristic of human ears. Noise at frequencies outside this bandwidth has minimal effect on masking a tone at any given critical band's center frequency.

Cycle - A cycle of a periodic function is the complete sequence of values that occur in a period.

Cycle per second - see Frequency.

Decibel (dB) - The decibel is a convenient means for describing the logarithmic level of sound intensity, sound power, or sound pressure above arbitrarily chosen reference values.

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*This glossary has been adapted from the EPA Report "Noise Training Manual," by P.L. Michael et al, December 1977.

Diffuse Sound Field - A diffuse sound field has sound pressure levels that are essentially the same throughout, and the directions of propagation are wholly random in distribution.

Effective Sound Pressure - The effective sound pressure at a given location is found by calculating the root-mean square value of the instantaneous sound pressure measured over a period of time at that location.

Free field - In a free field, sound that is radiating from a source can be measured accurately without interference from the test space. Absolute free-field conditions are rarely found, except in expensive anechoic (echo-free) test chambers; however, approximate free-field conditions exist in any homogeneous space where the distance from reflecting surfaces to the measuring location is much greater than the wave lengths of the sound that is being measured.

Frequency - The frequency of sound describes the rate at which complete cycles of pressure are produced by the sound source. The unit of frequency is the cycle per second (cps) or preferably, the hertz (Hz). The frequency range of the human ear is highly dependent upon the individual and the sound level, but a person with normal hearing will have a frequency range of approximately 20 to 20,000 Hz at moderate sound levels. The frequency of a sound wave that is heard by a listener is the same as the frequency of the vibrating source if the distance between the source and the listener remains constant; however, the frequency detected by a listener increases or decreases as the distance from the source decreases or increases (Doppler effect).

Hertz - see Frequency.

Infransonic Frequency - Sounds of an infrasonic frequency are below the audible frequency range.

Intensity - see Sound Intensity.

Level - The level of any quantity, when described in decibels, is 10 times the logarithm of the ratio of that quantity to a reference value.

Loudness - The loudness of sound is an observer's impression of its amplitude, which includes the response characteristics of the ear.

Noise - The terms "noise" and "sound" are often used interchangeably but, generally, sound is descriptive of useful communication or pleasant sounds, such as music; whereas, noise is used to describe dissonance or unwanted sound.

Noise Reduction Coefficient (NRC) - The noise reduction coefficient is the arithmetical average of the sound absorption coefficients of a material at 250, 500, 1000, and 2000 Hz.

Octave Band - An octave band is a frequency bandwidth that has an upper band-edge frequency equal to twice its lower band-edge frequency.

One-Third Octave Band - A frequency band whose cutoff frequencies have a ratio of 2 1/3, which is approximately 1.26. The cutoff frequencies of 891 Hz and 1123 Hz define a one-third octave band centered at 1000 Hz.

Peak Level - The peak sound pressure level is the maximum instantaneous level that occurs over any specified time period.

Period - The period (T) is the time (in seconds) required for one cycle of pressure change to take place; hence, it is the reciprocal of the frequency.

Pitch - Pitch is a subjective measure of auditory sensation that relates primarily to the frequency of a sound.

Power - see Sound Power.

Pure Tone - A pure tone is a sound wave whose instantaneous sound pressure is a simple sinusoidal function of time.

Random-Incidence Sound Field -see Diffuse Sound Field.

Random Noise - Random noise is made up of many frequency components whose instantaneous amplitudes occur randomly as a function of time.

Reverberation - Reverberation occurs when sound persists after direct reception of the sound has stopped. The reverberation of a space is specified by the "reverberation time," which is the time required, after the source has stopped radiating sound, for the rms sound pressure to decrease 60 dB from its steady-state level.

Root-Mean Square Sound Pressure - The root-mean-square (rms) value of a changing quantity, such as sound pressure, is the square root of the mean of the squares of the instantaneous values of the quantity.

Sound - see Noise.

Sound Intensity (I) - The sound intensity at a specific location is the average rate at which sound energy is transmitted through a unit area normal to the direction of sound propagation. The units used for sound intensity are joules per square meter per second. Sound intensity is also expressed in terms of a level (sound intensity level, L_I) in decibels referenced to 10^{-12} watts per square meter.

Sound Power (P) - The sound power of a source is the total sound energy radiated by the source per unit time. Sound power is normally expressed in terms of a level (sound power level, L_p) in decibels referenced to 10^{-12} watts.

Sound Pressure (p) - Sound pressure normally refers to the rms value of the pressure changes above and below atmospheric pressure when used to measure steady-state noise. Short-term or impulse-type noises are described by peak pressure values. The unit used to describe sound pressures is the pascal (Pa); 1 Pa equals 1 newton per square meter (N/m^2). Sound pressure is also described in terms of a level (sound pressure level, L_p) in decibels reference to 10^{-5} Pa.

Standing Waves - Standing waves are periodic waves that have a fixed distrbution in the propagation medium.

Transmission Loss (TL) - Transmission loss of a sound barrier may be defined as 10 times the logarithm (to the base 10) of the ratio of the incident acoustic energy to the acoustic energy transmitted through the barrier.

Ultrasonic - The frequency of ultrasonic sound is higher than that of audible sound.

Velocity - The speed at which the regions of sound-producing pressure changes move away from the sound source is called the velocity of propagation. Sound velocity (c) varies directly with the square root of the density and inversely with the compressibility of the transmitting medium as well as with other factors; however, in a given medium, the velocity of sound is usually considered constant under normal conditions. For example, the velocity of sound is approximately 344 m/sec (1,130 ft/sec) in air, 1432 m/sec (4,700 ft/sec) in water, 3962 m/sec (13,000 ft/sec) in wood and 5029 m/sec (16,500 ft/sec) in steel.

Wavelength - The distance required to complete one pressure cycle is called one wavelength. It may be calculated from known values of frequency (f) and velocity (c): $\lambda = c/f$.

White Noise - White noise has an essentially random spectrum with equal energy per unit frequency bandwidth over a specified frequency band.

APPENDIX C. TRAFFIC NOISE EXPOSURE IN THE COMMUNITY

C.1 Urban Traffic Noise Exposure

C.1.1 Noise exposure model

Estimates of the noise exposure caused by roadway traffic in urban areas nationwide have been generated by the EPA using the National Roadway Traffic Noise Exposure Model (NRTNEM) [C-1]. This computer model simulates the noise generated by traffic flow on the several categories of roads throughout the country, and estimates noise exposure by considering the distribution of the population relative to the roadway network and the characteristics of vehicles operating on that network. The baseline year for which detailed information on roadway traffic conditions, vehicle operational characteristics, and population distributions are input in the computer program is 1974. (The model makes estimates of noise exposure for later years by internally projecting these characteristics as necessary. For this report, the estimates obtained for 1980 are used.)

The model contains six functional classifications of roadways, with traffic flow characteristics broken down by place and size. Table C.1 lists the mileage, average daily traffic (ADT), and daily vehicle miles traveled (DVMT) in 1974 for each of the roadway classifications used in the model. The roadway mileage does not change from 1974 to 1980, but the ADT and DVMT are internally increased in the model by factors that reflect projections for the current number of vehicles on the road. These factors are a complex function of the different traffic mix in each place size/ roadway type category. Although the average overall vehicle growth factor between 1974 and 1980 is not calculated by the model, based on the increase in ADT and DVMT, it is estimated as approximately 20%.

TABLE C.1. 1974 DISTRIBUTION OF MILEAGE, ADT, AND DVMT [C-1].

Place* Size	Parameter	ROADWAY TYPE					
		Interstate	Other Freeway & Expressway	Major Arterials	Minor Arterials	Collectors	Local
>2M	Miles	1,998	1,749	9,861	14,103	12,854	84,247
	ADT	74,066	66,470	18,768	9,315	3,783	1,129
	DVMT	149,582,268	116,256,030	185,071,248	131,369,445	48,626,682	95,114,863
1M to 2M	Miles	1,869	1,527	5,156	10,219	10,308	64,678
	ADT	60,228	32,548	17,397	6,098	3,496	656
	DVMT	112,566,132	49,700,796	89,698,932	70,490,662	36,036,768	42,428,768
500k to 1M	Miles	1,477	739	4,034	6,320	7,190	47,466
	ADT	46,997	34,036	16,359	8,045	3,760	672
	DVMT	69,414,569	25,152,604	65,992,206	50,844,400	27,034,400	31,897,152
200k to 500k	Miles	1,743	1,076	5,566	8,569	7,897	58,252
	ADT	40,367	28,812	16,029	8,470	3,812	839
	DVMT	70,359,681	31,001,712	89,217,414	75,579,430	30,103,364	48,873,428
100k to 200k	Miles	854	803	3,851	5,502	5,714	36,697
	ADT	32,190	22,984	14,984	7,301	3,287	649
	DVMT	27,490,260	18,456,152	57,352,943	40,170,102	18,781,918	23,816,353
50k to 100k	Miles	512	600	3,335	4,445	4,534	29,284
	ADT	21,913	19,971	12,376	6,057	2,917	645
	DVMT	11,219,456	11,982,600	41,273,960	26,923,365	13,225,678	18,888,180
25k to 50k	Miles	397	447	4,282	5,377	5,828	33,454
	ADT	23,251	16,875	11,384	5,430	2,484	631
	DVMT	9,230,647	7,543,125	48,746,298	29,197,110	14,476,752	21,109,479
5k to 25k	Miles	899	1,099	9,652	12,124	13,130	75,431
	ADT	18,206	13,244	8,922	4,255	1,946	495
	DVMT	16,367,144	13,343,016	86,115,144	51,587,620	25,550,980	37,338,345
Rural	Miles	31,744	85,716	155,547	435,517	307,917	1,942,733
	ADT	13,700	4,623	2,523	899	370	98
	DVMT	434,892,800	396,265,068	392,445,081	387,174,613	113,929,290	190,387,834

NOTE: ADT = DVMT/MILES IS THE DERIVED QUANTITY

*Place Size in number of people (k = thousand, M = million).

Table C.1 includes data also for rural areas. These data are used in Sec. C.2 for rural noise exposure estimates.

In order to estimate the noise levels generated on this roadway network, the model uses four major categories of vehicles (light vehicles, trucks, buses, and motorcycles), which are further divided into 14 subcategories. For each of these subcategories, the model contains four operational modes: idle, acceleration, deceleration, and cruise. Data on the emission levels appropriate to each operating mode for each vehicle and the percentage of time that a vehicle is operated in a particular operating mode are included in the model. For each category of roadway, the model also contains data on the relative mix of vehicles.

The national urban population in 1980 is estimated in the model to be 160 million people.* It is divided among eight place sizes, with four population density categories for each place size. Table C.2 lists the population and areas associated with each of these categories (as well as for rural).

The noise level at a given distance from a particular roadway is determined by summation of the noise levels of the individual vehicles on that roadway. Depending upon the population density, one of three propagation curves is used to estimate the noise level at various distances away from the roadway. Using data on the distribution of traffic over 24- hour periods, the L_{dn}s at different distances from the roadways are determined.

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*1970 Series I projections.

TABLE C.2. 1980 POPULATION (IN MILLIONS) AND LAND AREA (IN SQUARE MILES) BY PLACE SIZE AND POPULATION DENSITY CLASS [C-1].

Population Density Category	Parameter	Place Size >2M	1M -2M	500k -1M	200k -500k	100k -200k	50k -100k	25k -50k	5k -25k	Urban Total	Rural
1	Population	6.06	2.25	0.39	1.64	1.18	1.09	0.48	1.89	14.98	71.88
	Area	134.2	272	63	215	217	329	58	220	1570.2	3,476,938
2	Population	24.06	4.37	2.18	10.64	2.99	2.16	3.04	5.07	54.51	0
	Area	3576	775	488	4558	1305	1115	896	1261	13,970.0	0
3	Population	23.32	11.91	8.99	6.88	6.98	4.62	3.58	8.63	74.91	0
	Area	8358	5080	4426	5790	5266	4195	2230	4527	39,872.0	0
4	Population	0	5.72	5.67	0	0	0	1.96	2.75	16.10	0
	Area	4089	4584	0	0	0	0	2769	5829	17,262.0	0
Total	Population	53.44	24.25	17.22	19.16	11.15	7.86	9.06	18.34	160.48	71.88
	Area	12,064.2	10,216.0	9561.0	10,563.0	6850.0	5639.0	5953.0	11,828.0	72,674.2	3,476,938

Total Population = 232.36 million

Total Land Area = 3,549,612.2 sq miles

The model also considers both primary and secondary exposure; that is, the primary exposure of a person to the noise of a roadway adjacent to his residence, and the secondary exposure to the variety of roadways in the nearby vicinity of his residence. The primary exposure is determined by considering the location of people relative to roadways. The secondary exposure is determined using a probabilistic approach based upon the ratio of land areas exposed to various levels of primary and secondary noise exposure. The primary and secondary exposures are summed to give the total exposure of residents in a particular area.

C.1.2 Noise Exposure Estimates

Using the model described in Ref. C-1*, estimates of the nationwide urban noise exposure have been developed. These are listed in Table C.3 for 1974 and 1980. As the table shows, due to increases in the population and in the number of vehicles on the road, the number of people exposed to various levels of roadway traffic noise is estimated to have increased by an average of 10 to 15%.

A breakdown of the exposure of people to urban traffic noise from various roadway types in different size towns is shown in Table C.4. These data were computed by the NRTNEM model for 1980 [C-1]. The bulk of the exposure occurs in places of 200,000 people or more. Major and minor arterials are the roadway types that contribute the most to roadway exposure.

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*Computations were performed in May 1980.

TABLE C.3. U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM URBAN TRAFFIC NOISE.

	Number (in Millions) of People*				
			Prior Estimates (C-2)		
	Current Estimates(C-1)		Streets	Freeways	
L_{dn}(dB)	1974	1980	1974	1976	Total
>80	0.1	0.1	0.1	0.4	0.5
>75	0.9	1.1	1.3	0.8	2.1
>70	4.8	5.5	6.9	1.3	8.2
>65	16.3	18.3	24.3	2.2	26.5
>60	39.8	43.8	59.0	3.5	62.5
>55	83.0	92.0	93.4	5.4	98.8

* Does not include rural exposure.

TABLE C.4. U.S. POPULATION (IN MILLIONS) EXPOSED TO 55 dB L_{dn} or HIGHER FROM URBAN TRAFFIC NOISE, BY PLACE SIZE AND ROADWAY TYPE*.

	Urban Place Size (No. of People)								
Roadway Type	2m	1m -2m	500k -1m	200K -500k	100k -200k	50k -100k	25k -50k	5k -25k	Total
Interstate	3.45	2.04	1.18	1.44	0.59	0.26	0.12	0.24	9.32
Other Highway	2.93	1.15	0.53	0.74	0.46	0.29	0.13	0.24	15.79
Major Arterial	7.79	2.62	1.88	2.66	1.65	1.20	1.11	2.22	21.13
Minor Arterial	7.78	3.39	2.15	2.94	1.65	1.05	1.11	2.29	22.36
Collector	5.61	2.99	2.01	2.01	1.11	0.67	0.96	2.00	17.36
Local	7.51	2.67	1.56	1.94	0.45	0.30	0.44	0.58	15.45
Total	35.07	14.86	9.31	11.73	5.91	3.77	3.87	7.57	92.09

* Data from May 1980 NRTNEM.

C.1.3 Comparison with Prior Estimates

In previous work for the EPA (C-2), a population density model of noise exposure was developed in which the mean L_{dn} in a census tract was determined by the following equation:

$$L_{dn} = 10 \log \rho + 22 \text{ dB}, \qquad (C.1)$$

where ρ is the population density of the census tract. Using this relationship and the assumption of a normal distribution of L_{dn} values throughout the census tract with a standard deviation of 4 dB, the distribution of the national urban population as a function of L_{dn} was determined (this distribution is appropriate to the 134 million people contained within census tracts in the 1970 census). Table C.3 lists this distribution.

This population density model provides an estimate of the L_{dn} away from major noise sources such as highways and airports. In order to estimate the nationwide exposure to traffic noise in urban areas, the noise generated by major highways and freeways must be added to the estimates determined from the population density model. Estimates of the nationwide exposure due to freeway noise are provided in the EPA Background Document for medium and heavy truck noise emission regulations [C-3]. The distribution of people versus L_{dn} is also listed in Table C.3. As can be seen from the table, the combined distributions are slightly higher than the estimates derived using the most recent traffic noise exposure model.

C.2 Rural Traffic Noise Exposure

Estimates of the noise exposure of people in rural areas are derived from a special model developed for this purpose rather than from the EPA NRTNEM model for a number of reasons. First, the population located near major rural roads must be known with more precision than a general population density model can provide. Second, the actual locations of homes relative to rural roads depends in a complex way on the type of roadway and the terrain between the road and the home. Third, rural population densities vary greatly from region to region; therefore using the national average figures of the NRTNEM would introduce errors in the total exposure estimates.

The rural model described below requires two major components: (1.) day-night sound level estimates at varying distances from each roadway, and (2.) the distribution of people as a function of distance for each of these roads.

Day-night sound level estimates are rather straightforward to obtain because of the availability of noise prediction models and information about the traffic characteristics on roadways in rural areas. However, before this study was undertaken, data that described the distribution of people in rural areas along rural roadways were not available.

In order to obtain information on the location of residences relative to rural roadways, 451 miles of roadways were surveyed in three different states (described below). From the resulting distributions, the percentage of dwellings located within different distance ranges from the roadway were determined for different roadway and terrain types, for distances corresponding to various L_{dn} values. The linear density in people per mile of roadway was determined as well. From these data, estimates of the nationwide noise exposure were derived, as described in the following section.

C.2.1 Noise exposure model

A recent tabulation of roadway statistics published by the Federal Highway Administration [C-4] provides information about the number of miles of roadway in rural areas, classified by both roadway type and by the type of terrain surrounding the roadway. This information was gathered from data provided by 46 states. The roadway classifications are interstate, other principal arterial, minor arterial, major collector, minor collector, and local. The terrain types are flat, rolling, and mountainous.

Review of the traffic characteristics of the roadways indicated that the low traffic flow on minor collectors and local roadways in rural areas would not result in noise exposures of significant interest in this study, and therefore these roads were eliminated from further consideration.

For each of the four remaining types of roadways, estimates of the L_{dn} at 50 ft were made using the latest modification of the TSC traffic noise prediction model [C-5]. These sound levels and the traffic characteristics used to make estimates are listed in Table C.5. There are two sources for these data as indicated in the table. The primary source is a Federal Highway Administration document that provides statistics from 46 states [C-4]. The second source is the EPA study [C-1] from which the National Roadway Traffic Noise Exposure

TABLE C.5. TRAFFIC CHARACTERISTICS AND DAY-NIGHT SOUND LEVELS FOR RURAL ROADWAYS.

Roadway Type	ADT*	% Trucks†	Average Speed (All Vehicles) (mph)†	L_{dn} at 50 ft (dB)
Interstates	13,700	17	55.8	77.5
Other Principal Arterials	4,623	14	51.9	72.5
Minor Arterials	2,523	11	50.6	68.5
Major Collectors	889	9	45.8	62.5

* Source: Ref. C-1

† Source: Ref. C-4, for medium and heavy trucks.

Model (NRTNEM) discussed in the last section was developed, which contains traffic data extrapolated to all of the states. (Note that the four categories of roadway used here correspond to the first four categories in Table C.1.) NRTNEM utilizes different ratios of medium to heavy trucks, depending on the urban place size, the roadway type, and the year of analysis. The baseline ratios range from 1:6 for interstates in rural areas to 7:5 for minor arterials in urban areas. For most roadway types and place sizes, an appropriate approximation is 50% medium trucks and 50% heavy trucks. This ratio is assumed to apply to all roadway types in this model. NRTNEM assumes that 87% of daily traffic occurs during daytime hours, and 13% occurs at night. In this application, we have assumed that 90% of the traffic occurs during daytime hours.

C.2.2 Population distribution characteristics

The distribution of residences in rural areas varies considerably. Farm areas would be expected to have a lower density than non-farm areas, and major terrain differences might also be expected to contribute to the variability of densities.

Five different areas were chosen for survey purposes: Connecticut (rolling terrain), Central Illinois (flat terrain), Northern California (mountainous terrain), Central California (flat terrain), and Coastal California (mountainous terrain).

In each of the five areas, aerial photographs taken before 1977 of several roadways were reviewed. The distance from individual dwellings to the center of each road was tabulated, for distances back from the roadway of between 1000 and 2000 ft. Table C.6 lists the roadways and mileages sampled, categorized by terrain type and type of facility (interstates and

TABLE C.6. RURAL ROADWAYS SURVEYED.

	Flat Terrain		Rolling Terrain	Mountainous Terrain
Roadway Type	California	Illinois	Connecticut	California
Interstate and Other Principal Arterials	Rts.99, 101, 198 96.4 miles	I-55 11.5 miles	I-86 13.4 miles	I-80 50.6 miles
Minor Arterials	Rts.41, 65 17.7 miles	Rts.36, 67, 123 25.8 miles	Rts.44, 63 8.6 miles	Rts.46, 49 105.8 miles
Major Collectors	Rt.246 15.3 miles	Rts.123, 613 15.6 miles	Rt.63 17.3 miles	Rts.1, 46 72.9 miles

other principal arterials have been grouped together as one facility type for this classification). Note that every combination of terrain type and facility type was surveyed, with two sets of data obtained for each facility for flat terrain.

C.2.3 Noise exposure estimates

The distances to L_{dn} values of 75, 70, 65, 60, and 55 dB were determined assuming a 4.5-dB dropoff per doubling of distance, typical of traffic noise propagation over rural terrain [C-6]. Table C.7 lists the distance ranges corresponding to 5-dB increments of L_{dn} for each roadway category. Also listed in the table are the percentages of residences within each 5-dB increment, determined from the distribution of residential distances obtained during our survey of rural roads. Since the rural population does not change greatly from year to year, no adjustment is made to reflect 1980 conditions.

Table C.8 lists the nationwide mileage of each roadway type by terrain category and the linear density of residences along these roadways, as determined from our sampling. (For flat terrain, the linear densities are averages of the densities determined in California and Illinois.) The mileages were obtained by multiplying the total mileage for a particular facility type [C-1] by the relative proportion of mileages by terrain type applicable to the 46-state date [C-4].

Since we wish to scale the data collected in California, Illinois, and Connecticut to the nation as a whole for individual terrain types, the linear densities must be adjusted to reflect the differences in the particular states from the total country. Table C.9 lists the total rural linear density (the

TABLE C.7. DISTRIBUTION OF RURAL RESIDENCES BY NOISE EXPOSURE RANGE.

Roadway Type	Ldn Range (dB)	Distances (Ft)	Percentage of Residences Along Roadway		
			Flat	Rolling	Mountainous
Interstates	70-75	80-160	15	0	3
	65-70	160-360	43	17	34
	60-65	360-760	20	50	53
	55-60	760-1660	15	29	9
Other Principal Arterials	70-75	0-80	1	0	0
	65-70	80-160	15	0	3
	60-65	160-360	43	17	34
	55-60	360-760	20	50	53
Minor Arterials	70-75	0-40	0	15	15
	65-70	40-80	0	44	27
	60-65	80-180	41	31	32
	55-60	180-400	33	10	24
Major Collectors	70-75	0-20	0	0	0
	65-70	20-40	1	3	7
	60-65	40-80	15	36	16
	55-60	80-160	32	47	23

TABLE C.8. NATIONAL MILEAGE OF RURAL ROADS AND RESIDENTIAL DENSITY ALONG THEM.

Roadway Type	Terrain Type	Number of Miles Nationwide	Linear Density in Residences/Mile
Interstate	Flat	15,429	4.85
	Rolling	14,190	3.74
	Mountainous	2,095	2.29
Other Principal Arterials	Flat	31,715	4.85
	Rolling	47,144	3.74
	Mountainous	6,857	2.29
Minor Arterials	Flat	53,042	4.29
	Rolling	87,262	16.74
	Mountainous	15,244	3.27
Major Collectors	Flat	138,930	5.38
	Rolling	258,697	7.91
	Mountainous	37,890	1.76

TABLE C.9. LINEAR DENSITY SCALING FACTORS.

	Total Rural Linear Density (People/Mile of Road)	Scaling Factor
United States	20.5	
California	24.0	0.85
Illinois	18.9	1.08
Connecticut	87.8	0.23

number of people living in rural areas divided by the total rural mileage), for the nation as well as the three states of interest [C-4]. From the table, it can be seen that the linear densities of the rural population in California and Illinois are not much different from the national rural linear density; but the density in Connecticut is more than four times the national density. We can then use the appropriate state scaling factor, determined by dividing the U.S. density by the state density, to adjust the linear densities in Table C.8. These scaling factors are shown in Table C.9.

As an example, the linear density for interstates in flat terrain areas (Table C.9) is adjusted by an average (Table C.6) of the California and Illinois scaling factors (Table C.9):

$$4.85 \times (0.85 + 1.08)/2 = 4.68 \text{ residences/mile.} \qquad (C.2)$$

Similarly, linear density for interstates in rolling terrain areas is adjusted by the Connecticut scaling factor:

$$3.74 \times 0.23 = 0.86 \text{ residences/mile} \qquad (C.3)$$

The linear density for interstates in mountainous terrain areas is adjusted by the California scaling factor:

$$2.29 \times 0.85 = 1.95 \text{ residences/mile.} \qquad (C.4)$$

Linear densities for the other roadway types are adjusted in a similar fashion.

Multiplying the adjusted linear density by the national number of miles for each roadway provides the number of residences along each roadway type. Then, applying the percentage of residences within each 5 dB range of day-night sound level appropriate to the particular facility/terrain type, the number of residences exposed to various levels of L_{dn} nationwide are obtained. For example, the number of residences along interstates in flat terrain areas is (from Eq. C.2 and Table C.8):

$$4.68 \times 15,429 = 72,208 \text{ residences.} \qquad (C.5)$$

The number of residences in the 70 to 75 dB L_{dn} range along interstates in flat terrain areas is (from Eq. C.5 and Table C.7):

$$72,208 \times 0.15 = 10,831 \text{ residences.} \qquad (C.6)$$

The values for each terrain category are summed for each roadway type and 5 dB L_{dn} range. The results of this analysis are contained in Table C.10.

Using an average occupancy of 3.1 people per residence for 1970 [C-7], the cumulative distribution of people exposed to various L_{dn} values is obtained from the statistical distribution of residences shown in Table C.10 and is listed in Table C.11. Table C.11 also lists population exposure estimates to urban traffic from Table C.3, as well as the combined U.S. population traffic noise exposure estimates.

TABLE C.10.NATIONWIDE DISTRIBUTION OF RURAL RESIDENCES BY NOISE EXPOSURE RANGE.

	Number (in Thousands) of Residences				
Ldn Range (dB)	Interstate	Other Principal Arterials	Minor Arterials	Major Collectors	All Roads
70-75	11.0	1.5	56.8	0	69.3
65-70	34.6	22.7	159.3	25.2	241.8
60-65	22.7	75.4	207.3	284.7	590.1
55-60	14.8	57.1	115.9	460.7	648.5

TABLE C.11. U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM TRAFFIC ON URBAN AND RURAL ROADS.

L_{dn} (dB)	Number (in Millions) of People		
	Urban	Rural	Total
>80	0.1	0.0	0.1
>75	1.1	0.0	1.1
>70	5.5	0.2	5.7
>65	18.3	1.0	19.3
>60	43.8	2.8	46.6
>55	92.0	4.8	96.8

REFERENCES FOR APPENDIX C

C-1 U.S. Environmental Protection Agency, "National Roadway Traffic Noise Exposure Model," Science Applications Inc. report prepared for the Environmental Protection Agency, November 1979.

C-2 W. Galloway, K. Eldred, and M. Simpson, "Population Distribution of the United States as a Function of Outdoor Noise Level," EPA Report 550/9-74-009, June 1974.

C-3 U.S. Environmental Protection Agency, "Background Document for Medium and Heavy Truck Noise Emission Regulations," EPA Report 550/9-76-008, March 1976.

C-4 U.S. Department of Transportation/Federal Highway Administration, "National Highway Inventory and Performance Study Summary," FHWA-PL-78-006, December 1977.

C-5 U.S. Department of Transportation/Federal Highway Administration, "Users Manual: TSC Highway Noise Prediction Code: Mod-04," FHWA-RD-77-18, January 1977.

C-6 U.S. Department of Transportation/Federal Highway Administration, "FHWA Highway Traffic Noise Prediction Model," FHWA-RD-77-108, December 1978.

C-7 U.S. Department of Commerce, Bureau of the Census, "Statistical Abstract of the United States, 1977," September 1977.

APPENDIX D. AIRCRAFT NOISE EXPOSURE IN THE COMMUNITY

D.1 Noise Exposure Model

The noise exposure estimates listed below were derived from the model of air carrier aircraft noise exposure described in Ref. D-1. The approach taken in that document to estimating nationwide exposure was to categorize all air carrier airports into four "average" airports; calculate the exposure at each average airport; and scale the results to the entire nation.

The four categories of airports, termed "AVports," included:

- Airports that are candidates for SST operations
- Airports allowing all aircraft except SSTs
- Airports where four-engine jets do not operate, except for LaGuardia and Washington National Airports
- LaGuardia and Washington National Airports.

For each AVport category, an average runway and flight track configuration was defined, and average numbers of operations and fleet mix were determined.

Noise exposure contours were developed for each AVport using the average data and the Integrated Noise Model computer program [D-1]. Using data from the U.S. census, a population vs area relationship was developed; application to the area within each noise exposure contour resulted in an exposed population estimate for each AVport.

Finally, these results were extrapolated to the nation using scaling factors based on relative number of operations among the various AVport categories. The resulting noise estimates are shown in Table D.1.

In a subsequent study [D-2], these results were modified to include revised fleet operational information and population data and updated noise levels for certain types of aircraft. The modified estimates are also shown in Table D.1.

As a best current estimate of the nationwide noise exposure of air carrier aircraft, an average of these two estimates has been made, as shown in Table D.1.

The estimates of Refs. D-1 and D-2 do not provide exposure data below L_{dn} 65. In an attempt to extrapolate to L_{dn} 60 and 55 dB, use has been made of the results of a study [D-3] of the estimated noise exposure around 307 airports due solely to the operation of 727-100 aircraft. The estimated exposed population extended over a wide range of L_{dn} values and indicated the relative change in exposed population for the lower L_{dn} values. By matching the 727 results to the current model results at L_{dn} 65 and 70, estimates for L_{dn} 60 and 55 were derived. The resulting nationwide noise exposure estimates over the L_{dn} range from 55 to 80 dB are listed in Table D.1. Note that these estimates do not include exposure to general aviation or military aircraft operations.

TABLE D.1 ESTIMATES OF U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM AIR CARRIER AIRCRAFT NOISE

	Number (in Millions) of People*			
L_{dn} dB	Ref.D-1	Ref.D-2	Current Estimate	Estimate in Levels Document
>80	0.05	N/A	0.05	0.2
>75	0.3	0.3	0.3	1.5
>70	1.4	1.2	1.3	3.4
>65	5.2	4.2	4.7	7.5
>60	N/A†	N/A	11.5	16.0
>55	N/A	N/A	24.3	N/A

* Current estimates for L_{dn} between 80 and 65 dB are derived from average of Ref. D-1 and D-2 values. Values for 55-60 dB are derived as described in text.

† N/A = Not available from this Reference.

D.2 Comparison with Previous Estimates

The "Levels Document" [D-4] contained earlier estimates of aircraft noise exposure, for the L_{dn} range of 60 to 80 dB, based on several earlier studies. For comparison purposes, these estimates are also shown in Table D.1. The CARD study [D-5] estimated that 1500 square miles were exposed to levels in excess of an L_{dn} of 65 dB. This estimate was confirmed in the Title IV Report [D-6] by an independent assessment of the calculated contours for 27 airports [D-7], supplemented by additional contours for several other airports. On this basis, the Levels Document showed 7.5 million people exposed to 65 dB or higher (obtained by multiplying the CARD figure of 1500 square miles by the national median urban population density of 5000 people per square mile). Our current estimate of 4.7 million, based on the more recent model, is nearly 40% lower. The estimates for levels other than 65 dB in the Levels Document were extrapolated using relationships developed in a study for the President's Aviation Advisory Commission [D-8]. The current estimates again show lower numbers of people exposed. These lower current estimates are due to the fact that more quieter aircraft are being introduced into the fleet each year, and more noisier aircraft, such as the DC-8, are being phased out as their useful life comes to an end. In addition, standard flight profiles adopted by the American Transport Association have reflected increasing concern for noise control.

REFERENCES FOR APPENDIX D

D-1 C. Bartel and L. Sutherland, "Noise Exposure of Civil Air Carrier Airplanes through the Year 2000," Vol. 1, WR 78-11, February 1979.

D-2 K. Eldred, "Estimate of the Impact of Noise from Jet Aircraft Air Carrier Operations," BBN Report 4237, November 1979.

D-3 K. Eldred, "Aircraft Noise Goals," EPA report to be published.

D-4 "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," EPA 550/9-74-004, March 1974.

D-5 Joint DOT-NASA "Civil Aviation Research and Development Policy Study," DOT TST 10-4/NASA 265, March 1971.

D-6 "Report of the Administrator of the Environmental Protection Agency," Public Law 91-604, February 1972.

D-7 D.E. Bishop and M.A. Simpson, "Noise Exposure Forecast Contours for 1967, 1970, and 1975 Operations at Selected Airports," BBN Report No. 1863, prepared for Department of Transportation, Federal Aviation Administration Office of Noise Abatement, September 1970.

D-8 "Aircraft Noise Analyses for the Existing Air Carrier System," BBN Report No. 3318, submitted to Aviation Advisory Commission, September 1972.

APPENDIX E. CONSTRUCTION NOISE EXPOSURE IN THE COMMUNITY

In this section, estimates of construction noise exposure are presented. These estimates are based on the construction noise model described in the EPA "Background Document for Portable Air Compressors" [E-1].

E.1 Construction Activity Model

Construction activity in the United States involves a wide variety of equipment, operating conditions, work hours, and site locations. Some construction equipment, such as the pile driver, create a great deal of disruptive noise but are only used at a small fraction of construction sites for a relatively short period of time, primarily during one construction phase. Other equipment, such as a dump truck, are used in many types of construction projects from the initial clearing phase through the finishing phase.

To develop a model of the noise levels produced by each construction site as a whole, the following steps are taken, as shown in Tables E.1(a)-(d) [E-2]. First, noise levels are obtained for each of the 22 pieces of construction equipment that is found to be the most significant component of construction activity in the United States. Then, four types of construction are defined, based on the different activities observed in each type. These are residential, nonresidential, industrial, and public works. Next, activity at each site is divided into five phases: clearing, excavation, foundation, erection, and finishing. Then, the fraction of the total site construction time that each piece of equipment

TABLE E.1(a). USAGE FACTORS OF EQUIPMENT IN RESIDENTIAL CONSTRUCTION (1974)[E-1].

Equipment		Construction phase					L_{eq} (50') during work periods for each item, over one project
		Clearing	Excavation	Foundation	Erection	Finishing	
Air compressor	(81)*	-	0.1	-	-	0.25	68.7
Backhoe	(85)	0.02	0.2	-	-	0.02	69.5
Concrete mixer	(85)	-	-	0.4	0.08	0.16	76.5
Concrete pump	(82)	-	-	-	-	-	-
Concrete vibrator	(76)	-	-	-	-	-	-
Crane, derrick	(88)	-	-	-	-	-	-
Crane, mobile	(83)	-	-	-	0.10	0.04	69.5
Dozer	(87)	0.10	0.1	-	-	0.04	72.0
Generator	(78)	0.4	-	-	-	-	64.5
Grader	(85)	0.05	-	-	-	0.02	65.0
Paving Breaker	(88)	-	-	-	-	0.01	61.0
Loader	(84)	0.2	0.1	-	-	0.04	70.0
Paver	(89)	-	-	-	-	0.025	66.0
Pile driver	(101)	-	-	-	-	-	-
Pneumatic tool	(85)	-	-	0.04	0.1	0.04	72.5
Pump	(76)	-	0.1	0.2	-	-	63.0
Rock drill	(98)	-	0.005	-	-	-	65.5
Roller	(80)	-	-	-	-	0.04	59.0
Saw	(78)	-	-	0.04[2]†	0.1[2]	0.04[2]	68.5
Scraper	(88)	0.05	-	-	-	0.01	67.0
Shovel	(82)	-	0.2	-	-	-	65.5
Truck	(88)	0.04	0.1	-	-	0.04	70.0
		L_{eq} (50') per site during work periods =					82.0 dBA
Hours at site		24	24	40	80	40Σ =	208 hrs.
						=	26 days

Total number of sites = 514,424 (Table E.2)

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* Numbers in parentheses () represent average A-weighted noise levels at 50 ft.
† Numbers in brackets [ ] represent average number of items in use, if that number is greater than one. Blanks indicate zero or very rare usage.

TABLE E.1(b). USAGE FACTORS OF EQUIPMENT IN NONRESIDENTIAL BUILDING CONSTRUCTION (1974)[E-1].

Equipment		Construction phase					$L_{eq}(50')$ during work periods for each item, over one project
		Clearing	Excavation	Foundation	Erection	Finishing	
Air compressor	(81)*	-	1.0[2]†	1.0[2]	1.0[2]	0.4[2]	83.5
Backhoe	(85)	0.04	0.16	0.4	-	0.04	76.5
Concrete mixer	(85)	-	-	0.4	0.4	0.16	79.0
Concrete pump	(82)	-	-	0.08	0.4	0.08	74.5
Concrete vibrator	(76)	-	-	0.2	0.2	0.04	67.0
Crane, derrick	(88)	-	-	-	0.16	0.04	76.0
Crane, mobile	(83)	-	-	-	0.16[2]	0.04[2]	74.0
Dozer	(87)	0.16	0.4	-	-	0.16	78.0
Generator	(78)	0.4[2]	1.0[2]	-	-	-	75.0
Grader	(85)	0.08	-	-	-	0.02	63.5
Paving breaker	(88)	-	0.1	0.04	0.04	0.04	75.0
Loader	(84)	0.16	0.4	-	-	0.16	75.0
Paver	(89)	-	-	-	-	0.1	70.0
Pile driver	(101)	-	-	0.04	0.16[2]	0.04[2]	85.0
Pneumatic tool	(85)	-	-	0.04	0.16[2]	0.04[2]	76.0
Pump	(76)	-	1.0[2]	1.0[2]	0.4	-	76.5
Rock drill	(98)	-	0.04	-	-	0.005	78.0
Roller	(80)	-	-	-	-	0.1	60.5
Saw	(78)	-	-	0.04[3]	1.0[3]	-	76.5
Scraper	(88)	0.55	-	-	-	-	73.0
Shovel	(82)	-	0.4	-	-	-	72.0
Truck	(88)	0.16[2]	0.4	-	-	0.16	80.0

$L_{eq(50')}$ per site during work periods = 91.0 dBA

Hours at site	80	320	320	480	160 Σ =	1360 hrs.
					=	170 days

Total number of sites = 12,710 (Table E.2)

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* Numbers in parentheses () represent average A-weighted noise levels at 50 ft.

† Numbers in brackets [ ] represent average number of items if number is greater than one. Blanks indicate zero or very rare usage.

TABLE E.1(c). USAGE FACTORS OF EQUIPMENT IN INDUSTRIAL CONSTRUCTION (1974)[E-1].

Equipment	Construction phase					$L_{eq(50')}$ during work periods for each item, over one project
	Clearing	Excavation	Foundation	Erection	Finishing	
Air compressor (81)*	-	1.0	0.4	0.4	0.4	78.0
Backhoe (85)	0.04	0.16	0.4	-	0.04	76.5
Concrete mixer (85)	-	-	0.4	0.16	0.16	77.5
Concrete pump (82)	-	-	0.05	0.16	0.08	71.0
Concrete vibrator (76)	-	-	0.2	0.1	0.04	65.5
Crane, derrick (88)	-	-	-	0.04	0.02	70.0
Crane, mobile (83)	-	-	-	0.08	0.04	68.0
Dozer (87)	0.2	0.4	-	-	0.04	77.5
Generator (78)	0.4	0.4	-	-	-	68.5
Grader (85)	0.05	-	-	-	0.02	62.5
Paving breaker (88)	-	0.1	0.04	0.04	0.04	75.0
Loader (84)	0.16	0.4	-	-	0.04	74.5
Paver (89)	-	-	-	-	0.12	70.5
Pile driver (101)	-	-	0.04	-	-	81.0
Pneumatic tool (85)	-	-	0.04	0.1[3]†	0.04	76.0
Pump (76)	-	0.4	1.0[2]	0.4	-	53.0
Rock drill (98)	-	0.02	-	-	0.003	75.0
Roller (80)	-	-	-	-	0.1	60.5
Saw (78)	-	-	0.04[2]	0.1[2]	-	67.5
Scraper (88)	0.14	-	-	-	0.08	70.5
Shovel (82)	-	0.4	-	-	0.06	72.0
Truck (88)	0.16[2]	0.26[2]	-	-	0.16	78.5
	$L_{eq(50')}$ per site during work periods =					88.0 dBA
Hours at site	80	320	320	480	160Σ	= 1360 hrs. = 170 days

Total number of sites = 50,839 (Table E. 2)

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* Numbers in parentheses () represent average A-weighted noise levels at 50 ft.

† Numbers in brackets [ ] represent average number of items in use, if that number is greater than one. Blanks indicate zero or very rare usage.

TABLE E.1(d). USAGE FACTORS OF EQUIPMENT IN PUBLIC WORKS (STREETS, SEWERS, ETC.) (1974) [E-1].

Equipment		Construction phase					$L_{eq(50')}$ during work periods for each item, over one project
		Clearing	Excavation	Foundation	Erection	Finishing	
Air compressor	(81)*	1.0	1.0	0.4	0.4	0.4[2]†	79.0
Backhoe	(85)	0.04	0.4	-	-	0.16	74.5
Concrete mixer	(85)	-	-	0.16[2]	0.4[2]	0.16[2]	81.0
Concrete pump	(82)	-	-	-	-	-	-
Concrete vibrator	(76)	-	-	-	-	-	-
Crane, derrick	(88)	-	0.1	0.04	0.04	-	74.0
Crane, mobile	(83)	-	-	-	0.16	-	69.5
Dozer	(87)	0.3	0.4	0.2	-	0.16	79.5
Generator	(78)	1.0	0.4	0.4	0.4	0.4	75.0
Grader	(85)	0.08	-	-	0.2	0.08	74.0
Paving breaker	(88)	0.5	0.5	-	0.04	0.1[2]	80.5
Loader	(84)	0.3	0.3	0.2	-	0.16	76.0
Paver	(89)	-	-	0.1	0.5	-	81.5
Pile driver	(101)	-	-	-	-	-	-
Pneumatic tool	(85)	-	-	0.04[2]	0.1	0.04	72.5
Pump	(76)	-	0.4[2]	1.0[2]	0.4[2]	-	75.5
Rock drill	(98)	-	0.02	-	-	-	82.5
Roller	(80)	-	-	0.01	0.5	0.5	73.5
Saw	(78)	-	-	0.04[2]	0.04	-	63.5
Scraper	(88)	0.08	-	0.2	0.08	0.08	78.0
Shovel	(82)	0.04	0.4	0.04	-	0.04	71.0
Truck	(88)	0.16[2]	0.16	0.4[2]	0.2[2]	0.16[2]	84.5
		$L_{eq(50')}$ per site during work periods =					91.0 dBA
Hours at site:		12	12	24	24	12 Σ =	84 hrs. = 10 ½ days

Total number of sites = 485,224 (Table E.2) spends in its normal operating mode is estimated for each phase, and a corresponding site duration equivalent noise level (L_{eq}) is computed. Finally, these Leq's for each piece of equipment are logarithmically summed to yield an average site L_{eq} for that type of construction.

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* Numbers in parentheses () represent average A-weighted noise levels at 50 ft.

† Numbers in brackets [ ] represent average number of items in use, if that number is greater than one. Blanks indicate zero or very rare usage.

For each of the four types of construction sites in Tables E.1(a) through E.1(d), the L_{eq} (at 50 ft) for an 8-hour work period is calculated, and the time at each work site is shown. The number of work sites indicated in the table is based on 1970 metropolitan construction activity shown in Table E.2 [E.1]. The sound level data came from open literature, manufacturers' reports, and EPA-solicited measurements.

E.2 Population Distribution

An EPA report (NTID 300.1)[E-2] includes data on the population distribution for various regions. These data are summarized in Table E.3.

The data from Tables E.2 and E.3 are used to determine the average population density in the neighborhood of different types of construction. The average population density (ρ), weighted by the number of sites in each region, is calculated with the following equation [E-1]:

$$\rho = \frac{1}{S} \sum_{n=1}^{5} S_n \rho_n, \qquad (E.1)$$

where S_n is the number of construction sites of a given type in metropolitan region n, ρ_n is the daytime population density in region n, and S is the total number of construction sites of a given type. The results of this calculation are shown in Table E.4.

TABLE E.2. ANNUAL CONSTRUCTION ACTIVITY IN METROPOLITAN REGIONS FOR 1970 [E-1].

Metropolitan Regions	Number of Sites			
	Residential Buildings	Nonresidential and Industrial Buildings***	New Municipal Streets, Sewers And Water Lines	Replacement of Sewers And Water Lines
Large high-density central cities	8,708 *	1,952 *	2,184 **	1,000 **
Large low-density central cities	21,578 †	4,903 †	17,200 †	7,920 **
Other central cities	102,559 †	12,021 †	48,000 **	21,600 **
Urban fringe	262,800 †	30,915 †	94,400 †	40,520 **
Met. area outside urban fringe	118,779 †	13,758 †	173,600 †	78,800 **
Totals	514,424 *	63,549 *	335,384 [E-4]	149,840 ††

* Reference [E-3] and unpublished data from the U.S. Bureau of Census.

† Apportioned by population density.

** Apportioned through a correlation developed at BBN for 24 cities, relating miles of street per square mile to population density; assumed constant ratio of miles of new road to miles of existing road, assumed 8 sites per mile.

†† Extending trend for Boston area to 550,000 miles [E-5] of existing road: 2% of existing road mileage for water lines, 1.5% of existing mileage for sewers, 8 sites per mile.

*** 80% assumed to be Industrial Buildings, 20% Nonresidential Buildings.

TABLE E.3. GEOGRAPHIC DISTRIBUTION OF POPULATION AND POPULATION DENSITY (1970)[E-1].

Region	Population †	Area (sq miles) [E-6]	Nighttime Population Density (people per sq miles)	Daytime Population Density (people per sq mile) **	Population Density (people per 1/8 linear mile) **,††
12 Large high-density central cities	22,250,000	1,468	15,160	16,650	120
14 Large low-density central cities	10,530,000	2,389	4,410	4,860	40
186 Other SMSA's *	25,820,000	6,981	3,710	4,070	32
Urban fringe	49,680,000	14,707	3,380	3,100	24
Met. area outside urban fringe	22,320,000	179,276	125	114	-

Total population in or near cities = 130,600,000.

* Standard Metropolitan Statistical Areas - groups of contiguous counties which contain at least one central city of 50,000 inhabitants or more, or "twin cities" with a combined population of 50,000 or more.

† Population figures were extrapolated from 1960 Census figures [E-7] according to recent growth rates.

** Takes into account the net population transfer from the suburbs to the central city during the normal working day. This net transfer was derived from 1960 Census figures [E-7] adjusted to 1970 according to recent population growth.

†† Made use of a correlation developed at BBN for 24 cities, relating miles of street per sq mile to population density.

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TABLE E.4. AVERAGE POPULATION DENSITIES EXPOSED TO DIFFERENT TYPES OF CONSTRUCTION ACTIVITY [E-1].

	Residential Buildings	Nonresidential Buildings	Public Works and Highways
Average Population Density, $\langle\rho\rangle$ people per sq mile	2907	3189	1866

E.3 Noise Exposure Estimates

Population exposure to construction activity noise is determined by combining the construction site and population density data described in Tables E.1 and E.4.

For each construction site, it is assumed that all the noise sources may be combined at one location as a point source. For most sites, a 6 dB per doubling of distance dropoff rate is used from that point to determine the distance at which the L_{dn} level for the site is 55 dB. For nonresidential building construction sites, because of their size, a 3 dB per distance doubling dropoff rate out to 400 ft was assumed, and 6 dB per distance doubling thereafter. It is also assumed for all sites that the first 100 ft around the site centerpoint is unoccupied by the public. Using the distance where the L_{dn} is equal to 55 dB, the land area exposed to an L_{dn} of 55 dB or greater for each type of construction can be determined. Multiplying this land area by the average population density around each site, the number of people exposed to an L_{dn} of 55 dB or greater is determined. It is assumed that at each construction site, except the office site, only one-half of the nearby building occupants are exposed to construction noise. For office sites, the number of people is reduced to 25%; for such sites, the neighboring buildings are mostly office buildings in which only approximately one-quarter of the occupants are exposed to construction noise from the adjacent site.

The population noise exposure calculations are summarized in Table E.5. Included in Table E.5 is the annual L_{dn} at 50 ft, the radial distance to 55 dB L_{dn}, and the number of

TABLE E.5. CALCULATION OF POPULATION IMPACTED BY ANNUAL L_{dn} GREATER THAN 55 dB.

	Residential Construction	Nonresidential Building Construction	Industrial Construction	Street and Sewer Construction
Current Levels 8-hr L_{eq} (50 ft)	82 dB	91 dB	88 dB	91 dB
Average Days of Activity Per Year	26	170	170	10-1/2
Annual Outdoor L_{dn} (50 ft)	65.8 dB	82.9 dB	79.9 dB	70.8 dB
Distance Required for Attenuation to 55 dB	173 ft	3512 ft	879 ft	308 ft
Area Within Radius (Excluding first 100 ft)	0.002 sq mile	1.39 sq mile	0.09 sq mile	0.010 sq mile
Average Population Density for Site	2907/sq mile	3189/sq mile	3189/sq mile	1866/sq mile
Percent of Population Impacted	50	25	50	50
People Impacted Per Site (Rounded)	3	1396	137	9
Total Number of Sites	514,424	12,710	50,839	485,224
Total Population Impacted (Rounded)	1,700,000	14,100,000	7,000,000	4,300,000

people exposed to 55 dB (or greater) for each type of construction. In a similar manner, the number of people exposed to L_{dn} values of 60, 65, 70, and 75 dB can be determined for each type of construction. Table E.6 summarizes the total number of people exposed to various values of annual L_{dn}, grouped into residential exposure (from residential and street and sewer construction), nonresidential exposure (from nonresidential building and industrial construction), and the total for all construction sites.

TABLE E.6 U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM CONSTRUCTION NOISE

L_{dn}(dB)	Number of People in Millions		
	Residential	Non-Residential	Total
>75	---	0.1	0.1
>70	---	0.6	0.6
>65	---	2.1	2.1
>60	1.0	6.7	7.7
>55	6.0	21.5	27.5

APPENDIX E REFERENCES

E-1 "Noise Emission Standards for Construction Equipment, Background Document for Portable Air Compressors," EPA Report 550/9-76-004, Washington, DC, December 1975.

E-2 Bolt Beranek and Newman Inc., "Noise from Construction Equipment and Operation, Building Equipment, and Home Appliances," prepared for the Environmental Protection Agency, Report No. NTID 300.1, 31 December 1971.

E-3 Business and Defense Services Administration, "Construction Review," April 1971.

E-4 U.S. Department of Transportation, Federal Highway Administration," Highway Statistics/1969, Washington, D.C.

E-5 Bolt Beranek and Newman Inc., "Specialty Construction Trucks: Noise and Cost of Abatement," BBN Report No. 2566e, September 1973.

E-6 Homer Hoyt, "Urban Land Use Requirements 1968-2000," Homer Hoyt Institute, The American University, Washington, D.C., Research Monograph No. 1, 1968.

E-7 U.S. Department of Commerce, Bureau of the Census, "Census of Population: 1960."

APPENDIX F. RAIL NOISE EXPOSURE IN THE COMMUNITY

In this appendix, noise exposure estimates are developed for three distinctly different types of rail operations: railroad line operations, rapid transit operations, and rail yard operations.

F.1 Railroad Line Noise

F.1.1 Noise exposure model

The analysis of current noise exposure from railroad line operations in the United States is excerpted from the EPA Background Document for the noise emission standards for railroads [F-1].

According to this report, the national average train operations for urban areas are as follows:

- 4 freight trains per day, 2 per night, each 33 mph, 70 cars, 3 locomotives
- 2 passenger trains per day, 1 per night, each 36 mph, 6 cars, 1 locomotive.

Since the noise of passenger trains is about 10 dB lower than the noise of freight operations, passenger operations are omitted in the following analysis.

F.1.2 Noise levels and transmission path

The sound exposure level, L_s, for locomotives and rail cars at 100 ft is given by [F-1]:

$$L_s = 110 - 10 \log v + 10 \log n \text{ for locomotives} \quad (F.1)$$

$$L_s = 33 + 30 \log v + 10 \log t \text{ for rail cars,} \quad (F.2)$$

where v = train speed in mph
n = number of locomotives
t = rail car passby time in seconds.

For a train with a speed of 33 mph, 3 locomotives, and a passby time of 73 seconds (70 cars x 50 ft/car + 48 ft/sec), then L_s = 100 dB for locomotives and = 97 dB for rail cars, for a total L_s of [F-1]:

$$L_s = 10 \log (10^{100/10} + 10^{97/10}) = 102 \text{ dB.} \quad (F.3)$$

The day-night sound level at 100 ft from the track can be expressed as [F-1]:

$$L_{dn} = L_s + 10 \log (N_d + 10 N_n) - 49.4, \quad (F.4)$$

where N_d and N_n are the number of daytime and nighttime operations, respectively. For L_s = 102, N_d = 4, and N_n = 2, L_{dn} = 66 dB.

The noise propagation model for railroad noise utilized in Ref. F-1 is based upon a decrease of 4.5 dB per doubling of distance from the tracks. In addition, it is assumed that there is noise shielding due to structures and other obstacles amounting to 4.5 dB somewhere in the first 500 ft. The net attenuation can be approximated by a straight-line dropoff of 6 dB per doubling of distance.

F.1.3 Noise exposure estimates

From this attenuation model, the values of L_{dn} prevailing in strips of land along the track can be determined. For example, if $L_{dn} = 66$ dB at 100 ft, at 200 ft, $L_{dn} = 60$ dB (for a 6 dB per distance doubling attenuation). Similarly, for the 8000 miles of U.S. railroad track and a population density along this track of 2500 people per square mile [F-1], Table F.1 illustrates the means for determining the population exposed to various 5-dB ranges of L_{dn}.

TABLE F.1 DETERMINATION OF POPULATION EXPOSURES.

L_{dn} Range (dB)	Distances of Strip Boundaries from track (ft)	Width of Strip on one side of track (ft)	Aggregated Area of Strips in US (sq mile)	Population (millions)
65-70	65-116	51	155	0.387
60-65	116-207	91	276	0.690
55-60	207-367	160	485	1.213

The total numbers of people in the United States exposed to railroad noise at various L_{dn} levels or higher are provided in Table F.2.

TABLE F.2. U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM RAILROAD NOISE.

L_{dn} (dB)	Number (in Millions) of People
>65	0.39
>60	1.08
>55	2.29

F.2 Rail Rapid Transit Noise

F.2.1 Noise exposure model

Wayside noise level and population data for the nine major U.S. rail rapid transit systems are available in the literature [F-2, F-3, F-4]. These data are summarized in Table F.3 for surface operations and in Table F.4 for operations on elevated structures. The data are used to estimate noise impact due to rail rapid transit operations as described below.

Noise impact is described in terms of the number of people exposed to various values of the day-night average sound level (L_{dn}) resulting from rail rapid transit operations. Given the transit system L_{dn} data from Tables F.3 and F.4, an attenuation rate of 3 dB per doubling of distance is used to determine the distance to contours of 70 dB, 65 dB, 60 dB, and 55 dB for each transit system. The background ambient noise, defined here as the L_{dn} to all sources excluding train passages, is estimated by using the relation

TABLE F.3. SURFACE OPERATIONS NOISE DATA FOR RAIL RAPID TRANSIT [F-2].

Metropolitan Region	Transit System	L_{dn} at 50 ft (dB)	Pop. Density (people/sq miles)	Percent of Surface Operation (miles)	Percent of Surface Operation With Residential Land Use (%)**
Atlanta	MARTA	54*	3,316*	5.7†	50 (estimated)
San Francisco	BART	68.5	9,165	27.7	37.4
Chicago	CTA	75.5	30,980	39.8	25.3
Boston	MBTA	72.3	21,480	19.5	24.8
New York	NYCTA	75.4	54,000	22.7	50
Philadelphia	PATCO	63.3	6,400	9.3	39.7
Cleveland	RTA	75	14,470	17.3	18
Philadelphia	SEPTA	72.9	31,400	1.1	30.9
Washington, DC	WMATA	64*	6,310*	12.5†	10 (estimated)

* See Ref. F-3.

† See Ref. F-4.

**Based on either actual or zoned land use.

TABLE F.4. ELEVATED OPERATIONS NOISE DATA FOR RAIL RAPID TRANSIT [F-3].

Metropolitan Region	Transit System	Type of Elevated Structure*	Ldn at 50 ft (dB)†	Length of Elevated Operation (miles)
Atlanta	MARTA	Concrete (without noise barrier)	64	0.5
		Concrete (with noise barrier)	57	1.2
San Francisco	BART	Conrete	68	20.0
Chicago	CTA	Steel (Open Deck)	81	31.5
		Concrete	72	1.0
Boston	MBTA	Concrete/Steel	68	1.2
		Steel (Open Deck)	81	4.4
New York	NYCTA	Steel (slid web girders, open deck)	85	57.4
		Steel (lattice web girders, open deck)	81	0.3
		Concrete Viaduct	73	5.6
		Concrete Encased Steel	69	0.8
Philadelphia	PATCO	Concrete	69	0.9
Cleveland	RTA	—	—	0
Philadelphia	SEPTA	Steel/Concrete	76	7.2
		Concrete Viaduct	73	0.5
Washington,DC	WMATA	Concrete/Steel	67	4.5

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*See Ref. F-3 for detailed description.

†Estimated for average system speed and train length.

$$L_{dn} = 10 \log (\rho) + 22 \text{ dB}, \qquad (F.5)$$

where ρ = population density (people per square mile). Using the background noise estimated for each transit system route, the distance from the tracks where the transit system L_{dn} reaches a level 5 dB below the ambient is determined. This distance, within which the transit system adds more than 1 dB to the ambient noise environment, is chosen as the limit for considering population exposure to transit noise. In certain cases (e.g., densely built-up areas), population is limited to the first row of buildings.

Population exposure at each sound level is estimated from physical inventories, where available [F-3]. In the absence of such information, the population density is distributed uniformly in each area bounded by the L_{dn} contours and the length of transit routes with adjacent residential land use. Where the ambient L_{dn} is 5 dB greater than a given L_{dn} contour, no further population exposure is counted.

F.2.2 Noise exposure estimates

The population noise exposure estimates for each transit system are provided in Table F.5 for surface operations and in Table F.6 for elevated operations. The combined results for all U.S. rail rapid transit operations are summarized in Table F.7.

TABLE F.5. U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM SURFACE OPERATIONS OF RAIL RAPID TRANSIT.

Metropolitan Region	Transit System	Number of People Exposed to L_{dn} or Higher			
		70 dB	65 dB	60 dB	55 dB
Atlanta	MARTA	0	0	0	0
San Francisco	BART	0	2,000	6,400	20,100
Chicago	CTA	10,500	33,100	33,100*	33,100*
Boston	MBTA	1,700	5,300	16,700	16,700*
New York	NYCTA	20,100	63,600	63,600*	63,600*
Philadelphia	PATCO	0	0	500	1,500
Cleveland	RTA	1,300	4,300	13,500	13,500*
Philadelphia	SEPTA	200	600	600*	600*
Washington, DC	WMATA	0	0	200	600

* Ambient L_{dn} greater than transit L_{dn} minus 5 dB; no further population exposure to transit noise assumed.

TABLE F.6. U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM ELEVATED OPERATIONS OF RAIL RAPID TRANSIT.

Metropolitan Region	Transit System	Number of People Exposed to L_{dn} or Higher 70 dB	65 dB	60 dB	55 dB
Atlanta	MARTA	0	0	0	50
San Francisco	BART	30	1,500	8,900	17,700
Chicago	CTA	77,700	77,900	77,900*	77,900*
Boston	MBTA	800	1,500	2,100	2,100*
New York	NYCTA	246,000	252,600	252,600*	252,600*
Philadelphia	PATCO	20	100	300	400
Cleveland	RTA	—	—	—	—
Philadelphia	SEPTA	27,800	27,800*	27,800*	27,800*
Washington, DC	WMATA	0	0	0	0

* Ambient L_{dn} greater than transit L_{dn} minus 5 dB; no further population exposure to transit noise assumed.

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TABLE F.7. U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM U.S. RAIL RAPID TRANSIT SYSTEMS.

L_{dn}(dB)	Number (in Thousands) of People		
	Elevated*	Surface	Combined
>70	352	34	386
>65	361	109	470
>60	370	135	505
>55	379	150	529

*Ref. F-3.

F.3 Rail Yard Noise

F.3.1 Noise exposure model

Estimates of the nationwide noise exposure due to rail yard operations are taken from the EPA Background Document for the final revision to the Interstate Rail Carrier Noise Emission Standards [F-5]. The model involves:

1. Categorization of all rail yards by type and level of activity
2. Estimation of the number of people exposed to different L_{dn} levels at each of more than 200 rail yards for which noise source, activity information, yard configuration, and vicinity demographic data are available
3. Extrapolating these noise exposure estimates to all the yards in the country.

Rail yards are first categorized by type (hump or flat), function (classification, industrial, or small industrial), and activity rate (high, medium, or low traffic). This breakdown leads to the following eight categories:

- High traffic hump classification yards
- Medium traffic hump classification yards
- Low traffic hump classification yards
- High traffic flat classification yards
- Medium traffic flat classification yards
- Low traffic flat classification yards
- Industrial flat yards
- Small industrial flat yards.

These yard categories have different configurations, traffic volumes, and noise sources and thus different resulting community noise exposures as well.

The noise sources occurring in various yard types and functions are listed in Table F.8. In general, these can be classified as either stationary sources or moving sources. For these sources, the sound exposure level, L_s, can be calculated as follows:

$$L_s = L_{ave} \max + 10 \log \frac{\Pi D}{V}, \text{ for moving sources} \qquad (F.6)$$

$$L_s = L_{ave} \max + 10 \log t_{eff}, \text{ for stationary sources} \qquad (F.7)$$

where

L_{ave} max = average maximum A-weighted sound level during an event or work cycle, in dB,

D = shortest distance between stationary observer and source path, in ft,

V = source speed, in ft/sec

t_{eff} = effective duration, in sec.

The one-hour equivalent sound level, $L_{eq}(1)$, is related to the sound exposure level, which is referenced to 1 sec by:

$$L_{eq}(1) = L_s + 10 \log (1/3600 \text{ sec/hr}) = L_s - 35.6. \qquad (F.8)$$

Depending upon the operating characteristics of the source, the following expressions can be used to estimate the day-night sound level from each:

$$L_{dn} = L_s + 10 \log(N_d + 10 N_n) - 49.4, \qquad (F.9)$$

TABLE F.8. RAIL YARD NOISE SOURCES.

HUMP YARDS:

- Master Retarders (Includes Group, Intermediate, and Track)
- Hump Lead Switchers
- Inert Retarders
- Makeup Switchers
- Car Impacts
- Idling Locomotives
- Locomotive Load Test
- Refrigerator Cars
- Industrial and Other Switchers
- Outbound Trains (Road-Haul plus Local)
- Inbound Trains

FLAT CLASSIFICATION YARDS:

- Classification Switchers, both ends of yard
- Car Impacts
- Inbound Trains
- Outbound Trains (Road-Haul plus Local)
- Idling Locomotives
- Load Tests
- Refrigerator Cars

INDUSTRIAL AND SMALL INDUSTRIAL YARDS:

- Switch Engines
- Car Impacts
- Inbound Trains (Local)
- Outbound Trains (Local)

TOFC/COFC YARDS (ATTACHED TO ABOVE RAILYARDS):

- Crane/Lift
- Hostler Truck

where N_d and N_n are the number of daytime and nighttime events, respectively, or

$$L_{dn} = L_{eq}(1) + 10 \log (N_d + 10 N_n) - 13.8, \quad (F.10)$$

when N_d and N_n are the number of daytime and nighttime hours, respectively, that the source is operating.

The EPA's Environmental Photographic Interpretation Center (EPIC) analyzed the photographic imagery and U.S. Coast and Geodetic Survey Maps of 207 railyards, selected to represent the total of 4169 yards in the country. This analysis provided data concerning yard configuration and noise source location at each yard, land use type around each yard, and distances from rail noise sources to residential and commercial areas.

Further, a questionnaire was sent to the railroads that owned the sample railyards, soliciting data on types and number of sources at each yard, relative source location, and activity rates for each source.

F.3.2 Noise emission levels and transmission path characteristics

Table F.9 lists the noise levels at 100 ft for the railyard noise sources considered at each yard. Substituting these noise levels and associated activity levels in Eqs. F.9 and F.10 yields the L_{dn} for each source at 100 ft.

The L_{dn} at residential and commercial locations in the vicinity of each yard is determined from

$$L_{dn} = L_{dno} - 10 \log \left(\frac{D}{D_o}\right)^n - k_1(D - D_o) - k_2 - k_3 \quad (F.11)$$

F

TABLE F.9. RAIL YARD SOURCE NOISE LEVEL SUMMARY.

Noise Source	Number of Measurements	Level of Energy Average*, 100 ft L_{ave} (dB)	 L_{max} (dB)	$L_{eq}(1)$ or L_s at 100 ft (dB)
Master Retarder: Group, Track, and Intermediate	410	111	111	108 (t_{eff}=0.5 sec)
Inert Retarder	96	93	93	90 (t_{eff}=0.5 sec)
Flat Yard Switch Engine Accelerating	30	77	90	94 (v=4 mph or 6 ft/sec)
Hump Switch Engine, Constant Speed		78	90	95 (v=4 mph or 6 ft/sec)
Idling Locomotive	27	65 (<2500 hp)	65	66 (constant average level)
	55	67 (>2500 hp)	67	
Car Impact	164	99	99	94 (t_{eff}=.3 sec)
Refrigerator Car	27	67	73	67 (constant level)
Load Test (Throttle 8)	59	87	90	87 (constant level)
Crane Lift		79	83	106.5 (t_{eff}=10 min)
Hostler Truck		65	82	94.5 (t_{eff}=15 min)

*A-weighted: I_{ave} = work cycle or position average for intermittent or moving sources.

I_{max} = average or expected maximum noise level during an event or work cycle.

where

L_{dno} = L_{dn} at D_o (100 ft), dB
D_o = 100 ft
n = 1 for moving sources
2 for stationary sources
k_1 = combined air and ground absorption coefficient in dB/ft
k_2 = industrial structures insertion loss
k_3 = residential structures insertion loss.

The k_1 value is a function of the spectral characteristics of the noise sources. The values of k_2 and k_3 depend on the land use and average population density, respectively, in the vicinity of the yard.

F.3.3 Population distribution characteristics

Around each yard, a rectangular study area was defined extending the length of the yard and out a distance of 2500 ft on both sides of the yard for most of the yards (a distance of 5000 ft on both sides was used for large classification yards). For all 207 yards, the estimated 1980 population within the study area (extrapolated from 1970 census figures), was divided by the area of the rectangular region (excluding the area of the rail yard). The resulting average population density, in people per square mile, was used to estimate the population noise exposure around each yard, as described in the next section.

F.3.4 Noise exposure estimates

A computer program has been developed to perform the necessary noise exposure calculations. For each yard, the following information is utilized by the program:

- Rail source noise emission levels (from Table F-9)
- Rail source activity information (from the yard questionnaires)
- Rail yard configuration/source location (from the yard questionnaires and EPIC analysis)
- Distances to residential and commercial land use (from EPIC analysis)
- Population density around the yard (from the population analysis).

For each source, the L_{dn} is calculated at different distances using Eqs. F.9, F.10, and F.11.

For example at 1000 ft from a master retarder through which 1000 cars are classified each day, if each car generates a squeal, from Eq. F.9 and Table F.9:

$$\begin{aligned} L_{dn} \text{ (100 ft)} &= 108 + 10 \log(850+10\text{x}150) - 49.4 \\ &= 92.3 \text{ dB} \end{aligned}$$

where 85% daytime operations have been assumed.

If there are no structures between the master retarder and the observation point (i.e., k_2 and $k_3 = 0$), and a value of .01 is used for k_1, from Eq. F.11:

$$\begin{aligned} L_{dn} \text{ (1000 ft)} &= 92.3-10 \log(\frac{1000}{100})^2 - .01(1000-100) \\ &= 63.3 \text{ dB} \end{aligned}$$

The total L_{dn} is determined by summation of the L_{dn} values for all sources. Using the distances to various total L_{dn} values (e.g., 55, 60, 65, 70, and 75 dB) and the population density, the number of people exposed to different levels of L_{dn} are determined for each yard.

Finally, the results for each yard are extrapolated to all rail yards in the country, for all eight categories of yards. Table F.10 lists the number of yards throughout the United States that lie in each category.

Table F.11 lists the final results: the number of people nationwide exposed to various levels of total L_{dn} for all rail yard sources.

TABLE F.10. DISTRIBUTION OF RAIL YARDS BY YARD TYPE AND TRAFFIC RATE.

	Number of Railyards			
	Traffic Rate			
Yard Type	Low	Med	High	Total
Hump Classification	46	47	31	124
Flat Classification	571	357	185	1113
Industrial				1381
Small Industrial				1551
TOTAL				4169

F

TABLE F.11. U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM RAILROAD, RAIL RAPID TRANSIT AND RAIL YARD NOISE.

L_{dn} (dB)	Number (in Millions) of People Exposed			
	Railroad	Rail Rapid Transit	Rail Yard	Total
>70	--	0.4	0.4	0.8
>65	0.4	0.5	1.6	2.5
>60	1.1	0.5	1.9	3.5
>55	2.3	0.5	3.2	6.0

REFERENCES FOR APPENDIX F

F-1 U. S. Environmental Protection Agency, "Background Document for Railroad Noise Emission Standards," EPA Report No. 550/9-76-005, December 1975.

F-2 G. Chisholm et al., "National Assessment of Urban Rail Noise," U.S. Department of Transportation, Report No. UMTA-MA-06-0099-79-2, March 1979.

F-3 D.A. Towers, "Noise Impact Inventory of Elevated Structures in U.S. Urban Rail Road Transit Systems," U.S. Department of Transportation, Report No. UMTA-MA-06-0099-80-5, September 1980.

F-4 *Modern Railroads: 1980 City-By-City Transit Digest*, May 1980.

F-5 U. S. Environmental Protection Agency, "Background Document for Rail Carrier Noise Emission Standard - Railyard Facility Emissions and Additional Sources," 18 August 1980, Draft.

APPENDIX G. INDUSTRIAL NOISE EXPOSURE IN THE COMMUNITY

G.1 Noise Exposure Model

The noise exposure in communities with neighboring industrial operations is considered as the sum of the individual exposures from every separate industrial facility. To discuss this nationwide noise exposure in manageable terms, it is necessary to compute an estimate of exposure for a simplified plant-neighbor relationship and then extrapolate the results to produce estimates of total U.S. population exposure.

Calculations are based on

- The acoustic power emitted by the industrial plant which is a function of the electrical energy used by that plant.
- The day-night sound level distribution around the plant, L_{dn}, which is a simple function of the acoustic power emitted by the plant.

In order to complete these calculations, it is also necessary to determine:

- The number of manufacturing plants
- The electrical energy used
- The efficiency of electrical energy conversion to radiated acoustic energy

- The day-night sound level distribution corresponding to the radiated acoustic energy of a plant

- The local population density.

The method does not include the exposure, assumed to be small, for onlookers--for example, people walking past an industrial plant. The noise exposure incurred by people working at these plants (occupational noise exposure) is discussed in Appendix K.

G.2 Noise Emission Levels

Individual industrial plant noise sources could be classified into categories, such as noise-generating process, industrial use, or sound power level, etc. Ultimately, all industrial plant major noise sources could be identified and listed this way. Such a listing is not presently available.

From a neighbor's viewpoint, noise sources can be grouped as to location, interior or exterior. Interior noise can be transmitted to a community through building openings--windows, doors, louvers--or by building walls. Interior noise transmitted to the community not only results in a transmission loss (usually greater than 10 dB), but often a loss of the identity of individual sources as well. Exterior sources are more frequently audible and identifiable in nearby communities than are interior noises.

Ranges of industrial machinery noise levels are shown in Table G.1 [G-1].

TABLE G.1.
RANGE OF INDUSTRIAL MACHINERY, EQUIPMENT AND PROCESS NOISE LEVELS [G-1].

Source	A-Weighted Noise Level at Operator Position dB
Pneumatic Power Tools	90-116
Molding Machines	101-106
Air Blown-Down Devices	91-104
Blowers and Fans	79-100
Air Compressors	93-100
Metal Forming Machines	81-97
Combustion Furnaces	81-97*
Turbo-generators	89-91†
Pumps	80-91
Industrial Trunks	89-90
Transformers	83-84

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* Measured 25 ft from source.

† Measured 10 ft from source.

Published data for fan noise and cooling towers [G-2, G-3] are supplemented by additional prediction methods [G-4] based on a review of individual machinery measurements conducted over the past 25 years. A representative mix of pumps, compressors, gearboxes, electric motors, diesel engines, fans, and cooling towers was chosen to produce an idealized prediction formula. The relationship between acoustic power and electric power energy consumption, chosen as representative for United States industry, is:

$$\mathrm{PWL(A)}^{*} = 88 + 10 \log_{10} \mathrm{hp}. \qquad \text{(G.1)}$$

G.3 Source Operating Characteristics

Many plants operate only one shift five days per week, while others, such as electric generating stations, often operate around the clock seven days per week. Based on discussions with individual utility companies, a schedule assumed for this analysis is an idealized plant operating 24 hours each day for six days a week.

G.4 Transmission Path

The transmission path between industrial sources and their neighbors can take many forms. Interior noise from well-enclosed plants with masonry or metal insulated walls can suffer transmission losses of at least 15 to 30 dB. Certain industrial plants, such as oil refineries, open electric generating stations, and aircraft assembly plants that are located in warm climates, have few or no enclosing walls. For this analysis, it is assumed that half the plants contain exterior noise sources only and half contain interior noise sources only. The latter will be considered to have a radiated sound level 15 dB less than that for the exterior noise source.[G-7]

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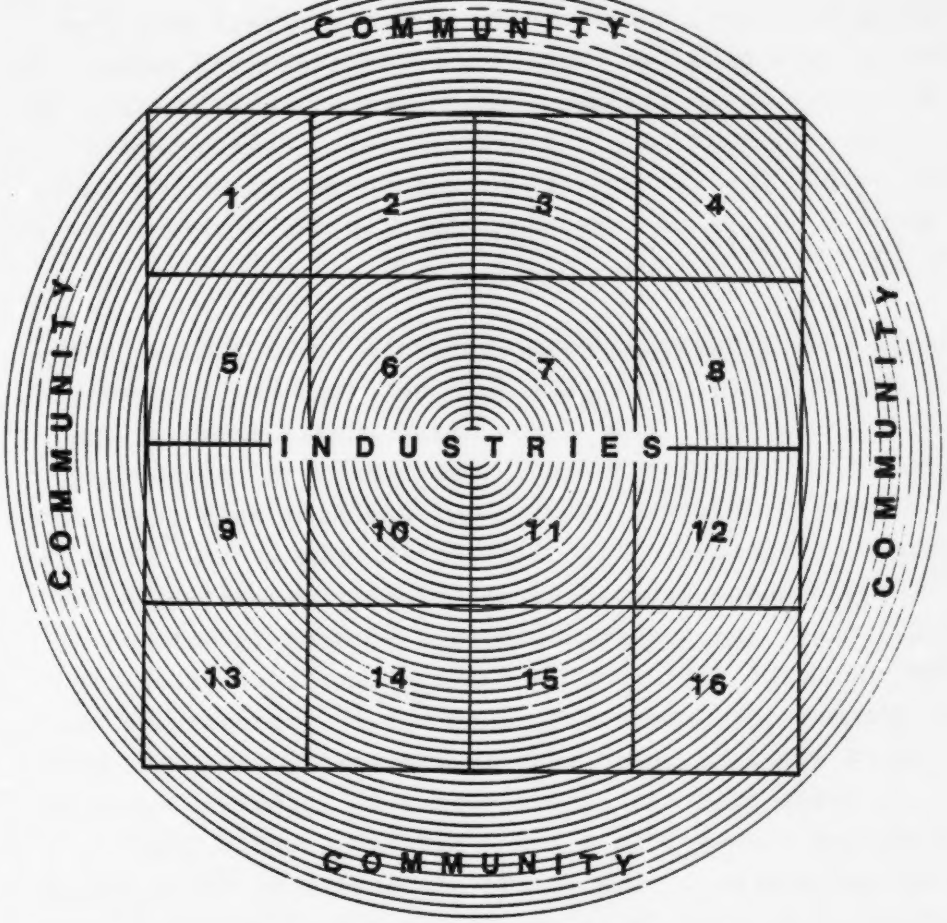
* Referenced to 10^{-12} watt.

Of the 320,700 industrial establishments [1972 total] in the United States [G-5], it is assumed that most are located reasonably close to the labor force within urban areas of the country. It is further assumed that industrial plants are often clustered together, partially shielding each other from residential neighbors. Also, industrial plants are often located along transportation routes, such as rivers, highways, or rail lines. The transmission path between industrial sources and their neighbors can have significant shielding within uninhabited intervening land areas. To estimate the fraction of acoustic power that is radiated toward residential areas, it seems reasonable to consider an industrial park with 16 industries arranged in a 4 x 4 matrix (see Fig. G-1). For the four industries on the corners, one-half of their property borders other industries and one-half borders the outside residential neighbors. The four industries in the center of the matrix have no common borders with the outside, and the remaining industries have one-fourth of their property bordering the outside. The average fraction of property bordering residential neighbors is, then, one-fourth, or 25%, in this example. Industrial areas with smaller numbers of industries grouped together have a greater percentage of common borders, while areas with more industries have a smaller percentage of common borders. However, in this analysis, it is assumed that one-quarter of the acoustic power from industrial facilities radiates toward inhabited areas.


COMMUNITY
COMMUNITY
COMMUNITY
COMMUNITY
INDUSTRIES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Industry #	Percent of Border Facing Community	Number of Industries
1, 4, 13, 16	50	4
2, 3, 5, 8, 9, 12, 14, 15	25	8
6, 7, 10, 11	0	4
Average	25	16

FIG. G.1. SCHEMATIC REPRESENTATION OF FRACTION OF INDUSTRIAL NOISE IMPINGING ON COMMUNITY.

It will also be assumed that shielding, from structures and other obstacles, amounts to 6 dB between plants and neighbors and that plant noise in urban areas decreases 6 dB per doubling of distance.

G.5 Population Distribution

The fraction of industrial plants that are located in urban areas is not known. In 1970, about 66% of the United States population lived in urban places with a population of 2500 or more, and 74% lived in all urban places [G-5]. Since industrial plants must be located near a large source of labor, a proportionally larger fraction of plants must be found in urban areas. As a reasonable estimate, it is assumed that 80% of all industrial plants are located in urban areas. It is further assumed that these urban areas have an average urban population density of 5000 people per square mile.

G.6 Noise Exposure Estimates

To estimate the noise exposure as a function of distance from industrial plants, we first find the average horsepower used by each plant. The number of operating minutes is taken over one year:

$$60 \text{ (min/hr)} \times 24 \text{ (hr/day)} \times 6 \text{ (day/wk)} \times 52 \text{ (wk)} = 4.49 \times 10^5 \text{ (min)}. \qquad \text{(G.2)}$$

In 1977, United States industry purchased 2.307×10^{15} BTU of electrical energy [G-5]. It is assumed that two-thirds of this energy drives noise producing machinery, giving a total noise-related horsepower per year of:

$$\begin{aligned} \mathrm{Hp} &= \mathrm{BTU} + \mathrm{min} \times \mathrm{hp/BTU/min} \\ &= 2.307 \times 10^{15}\ (\mathrm{BTU}) \times 2/3 \\ &\div (4.49 \times 10^{5}\ (\mathrm{min})) \times .02356\ (\mathrm{hp/BTU/min}) \\ &= 8.07 \times 10^{7}\ (\mathrm{hp}) \end{aligned} \tag{G.3}$$

where .02356 is the conversion factor from BTU-min to hp.

The sound power level emitted by each plant is given by (from Eq. G.1)

$$\begin{aligned} \mathrm{PWL} &= 88 + 10 \log (8.07 \times 10^{7}\ (\mathrm{hp/yr}) \\ &\quad + 3.207 \times 10^{5}\ (\mathrm{plants})) \\ &= 112.0\ \mathrm{dB.} \end{aligned} \tag{G.4}$$

The sound pressure level L at a distance d (in feet) from a noise source with a sound power level of PWL is given by Ref. G-6:

$$L = \mathrm{PWL} - 20 \log(d) - 0.6 + C,\ \mathrm{dB}, \tag{G.5}$$

where C is a temperature/pressure correction term with a range of about ± 0.5 dB over typical temperatures and pressures. In this formulation, the 20 log(d) term indicates an assumed attenuation rate over distance of 6 dB per doubling of distance. By ignoring the third and fourth terms of Eq. G.5 and substituting Eq. G.4, we have:

$$L = 112 - 20 \log(d),\ \mathrm{dB.} \tag{G.6}$$

It has been observed that in a typical industry situation the hourly usage of electrical energy during nighttime hours is about two-thirds of the use during daytime hours. The L_{dn} resulting from this usage pattern is then:

$$\begin{aligned} L_{dn} &= 10 \log \frac{1}{24} [15 \times 10^{L/10} + \frac{2}{3} \times 9 \times 10^{(L+10)/10}] \\ &= L + 10 \log (75/24) \\ &= L + 5,\ \mathrm{dB.} \end{aligned} \tag{G.7}$$

Substituting Eq. G.6 and subtracting 6 dB to account for shielding within the community results in a final equation for the community noise levels around industrial plants of:

$$L_{dn} = 111 - 20 \log(d). \qquad (G.8)$$

Assuming the minimum noise reduction of 15 dB found in residential buildings (see ref. G-7) applies to industrial sources inside the plant, it can be reasoned that these interior sources do not contribute to the noise exposure. We also assume that there are no residents within 150 ft of the plant.

The distances for various L_{dn} values are easily determined from Eq. G.8. We compute the area around the plant corresponding to a given L_{dn} and multiply by 1) 260,000 plants in urban areas, 2) 50% to account for external sources only, 3) a population density of 5000 people per square mile, and 4) 25% to account for noise radiated toward residential areas. The result is the number of people actually exposed nationwide to this particular L_{dn} value and higher.

As an example, the impacted area within the 60-dB contour is

$$\Pi\left[\frac{(10^{(111-60)/20})^2 - 150^2}{(5280)^2}\right] = 0.0117 \text{ sq miles} \qquad (G.9)$$

since the area of a circle of radius r is Πr^2, and $\Pi 150^2$ must be subtracted since there are no residents within 150 ft of the plant.

The population exposed to an L_{dn} of 60 dB or higher from industrial noise is therefore:

$$0.0117 \times 260{,}000 \times 0.5 \times 5000 \times 0.25 = 1.9 \text{ million.} \quad (G.10)$$

Similar calculations result in the distribution of people vs L_{dn} contained in Table G.2.

TABLE G.2. U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM INDUSTRIAL NOISE.

L_{dn}(dB)	Number (in Millions) of People
>65	0.3
>60	1.9
>55	6.9

REFERENCES FOR APPENDIX G

G-1 Administrator of the U.S. Environmental Protection Agency, "Report to the President and Congress on Noise," in compliance with Title IV of Public Law 91-604, The Clean Air Act Amendments of 1970, Senate Document 92-63, U.S. Government Printing Office, February 1972.

G-2 I. Dyer and L. Miller, "Cooling Tower Noise," Noise Control, May 1959.

G-3 J.B. Graham, "Fan Selection and Installation," ASHRAE Symposium paper June 1975, American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc., 345 East 47th Street, New York, NY 10017.

G-4 L. Miller, Lecture notes for course "Noise Control Techniques for Industrial and Manufacturing Plants," Bolt Beranek and Newman Inc., 1979.

G-5 U.S. Department of Commerce, Bureau of the Census, "Statistical Abstract of the United States: 1979," 100th Edition, Sept. 1979.

G-6 Cyril M. Harris, "Sound and Sound Levels," in Handbook of Noise Control (C.M. Harris, ed.), 2d edition, McGraw-Hill Book Co., New York, 1979.

G-7 U. S. Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," Report No. 550/9-74-004, March 1974.

APPENDIX H. AGRICULTURAL NOISE EXPOSURE IN THE COMMUNITY

H.1 Noise Exposure Model

Recognizing differences in farm size, population distribution, and character of farming operations, analyses were undertaken for four regions of the country. These regions were chosen to match the breakdown for which the most complete data were available from the "Statistical Abstract" [H-1 and H-2].

Table H.1 lists the number of different mechanical equipment, the resident population, and the density of farm population for each region. In each case, the latest data available were used, so the values cited in Table H.1 represent different years, as indicated. It should be noted that the number of people on farms has decreased from the 1970 figure given in the table to the 1978 figure of 8,005,000, and the total number of tractors has decreased to 4,370,000 [H-2] for 1978.

H.2 Noise Sources

The principal noise source on the farm is the tractor. The truck is quieter, more likely to be operated on roads (where it becomes part of the traffic population considered in Appendix C), and the combine and corn picker operate only for a short time during the harvest season.

Reference H-3 contains data on noise levels emitted by tractors. From these data, the A-weighted sound level of tractors at full power measured at 50 ft is

TABLE H.1. FARM REGION DATA.

Region	No. of Tractors (x1000)	No. of Trucks (x1000)	No. of Combines (x1000)	No. of Corn Pickers (x1000)	Farm Population (x1000)	Total Area (Sq.mi.x 10^3)	Population Density People/ Sq. Mi.
Northeast	314	158	14	33	699	41	17
North Central	2346	1335	354	481	4305	580	7.4
South	1301	1065	106	91	3754	506	7.4
West	507	480	50	9	954	514	1.9
TOTAL	4468	3038	524	614	9712	1641	5.9
Date of Data	1974	1974	1974	1974	1970	1979	
Reference	H-1	H-1	H-1	H-1	H-2	H-2	

$$L_A = 62 + 10 \log (hp), \qquad (H.1)$$

where L_A is the "A-weighted" sound level in decibels. It must be noted that variations of up to ±10 dB can be observed for particular tractors. In calculating noise exposure, initially only the sounds of tractors will be considered. The typical (average) tractor is of 54 hp, on the basis of reference H-2 for the total number of tractors in 1978 (4.370×10^6), and the total horsepower of tractors (238×10^6 hp). Therefore, from Eq. H.1, a tractor with 54 hp could be expected to generate the following levels during full power operations and during engine idle operations (assumed to be at 50% power):

$$L_A = 62 + 10 \log (54) = 79 \text{ dB full power} \qquad (H.2)$$

$$L_A = 62 + 10 \log (54) + 10 \log(0.5) = 76 \text{ dB idle.} \qquad (H.3)$$

Reference H-2 indicates that full power operations involve roughly 600 hours per year per tractor and idle operations involve about 200 hours per year.

Assuming that all of this activity takes place during daytime hours and noting that there are 5,475 daytime hours per year (between 7 a.m. and 10 p.m.), the average annual L_{eq} at 50 ft during the daytime for an average tractor at full power is then:

$$\begin{aligned} L_{eq} &= 79 + 10 \log \left(\frac{600 (hr)}{5475 \text{ (day-hr/yr)}} \right) \\ &= 69 \text{ dB}, \end{aligned} \qquad (H.4)$$

and at idle is:

$$L_{eq} = 76 + 10 \log \left(\frac{200(\text{hr})}{5475\ (\text{day-hr/yr})}\right)$$

$$= 62\ \text{dB}. \qquad \text{(H.5)}$$

The average annual L_{dn} at 50 feet is then:

$$L_{dn} = 10 \log \frac{1}{24} (15\ x(10^{69/10} + 10^{62/10}) + 9\ x\ 0)$$

$$= 68\ \text{dB}. \qquad \text{(H.6)}$$

Since the $L_{dn}(R)$ at a given distance R from the tractor is

$$L_{dn}(R) = L_{dn}(50\ \text{ft}) + 20 \log 50/R,\ \text{dB}, \qquad \text{(H.7)}$$

we can derive the distance at which a given L_{dn} occurs, as follows:

$$R = 50 \times 10^{(68-L_{dn})/20}. \qquad \text{(H.8)}$$

For example, the radius at L_{dn} = 65 dB is

$$R = 50 \times 10^{(68-65)/20} = 71\ \text{feet} \qquad \text{(H.9)}$$

The radii and impacted area values obtained in this way for L_{dn} 55, 60, and 65 are shown in Table H.2.

TABLE H.2. IMPACT OF AVERAGE TRACTOR.

Annual L_{dn} (dB)	Radius (ft)	Area of Impacted Area (sq miles)
>65	71	0.00056
60 - 65	126 - 71	0.00122
55 - 60	223 - 126	0.00383

H.3 Noise Exposure Estimates

The number of people in each region of the country exposed to various levels of noise is estimated in the following way. First, the number of tractors in each region is multiplied by the impact areas calculated in Table H.2. Then these values are multiplied by the appropriate regional population densities. For example, the area impacted by 65 dB L_{dn} or greater in the Northeast is:

$$314{,}000 \text{ tractors} \times 0.00056 \text{ sq miles/tractor} = 176 \text{ sq mi}, \quad (H.10)$$

and the population impacted is:

$$176 \text{ sq miles} \times 17 \text{ people/sq miles} = 2992 \text{ people}. \quad (H.11)$$

Finally, two adjustments are made that account for the assumptions that 1) tractors are operated in areas around the farm that have less than the average population density, and 2) machinery other than tractors add to the noise exposure. To obtain the first adjustment, we can assume that the population on a farm is geometrically distributed over the farm area. That is, half of the area has the average population density, one-fourth of the area has one-fourth the population density, and so on. For instance, if the tractor operates primarily in a low-density environment and the area above L_{dn} 55 dB from tractor noise is 1/20 of the total farm area, we assume the actual population density within the 55 dB contour is 1/20 of the average. Another way to view this adjustment is to assume that all the people on the farm are packed into an area the size of the 55-dB contour. Then, if the tractor spends equal time in each part of the farm, the average impacted population will be the average population density times the ratio of the contour area divided by the farm area.

To obtain the second adjustment, we assume that 50% of farm trucks and 100% of combines and corn pickers impact the farm population in the same way and at the same noise levels that tractors do. From Table H.1, this assumption results in a 40 to 64% increase in "equivalent" tractors, depending on the region. For simplicity, the second adjustment is assumed to be a 50% increase in the final adjusted values for all regions. The adjusted exposed population is shown in Table H.3.

Table H.4 summarizes the national distribution of people exposed to various levels of L_{dn} from agricultural machinery. These values might be further increased because over 45% of the workers in agricultural work live off the farm. Correspondingly, they might also be decreased because 49% of the employed persons living on farms work in urban areas at other than agricultural work and so are away from the farm during the day [H-5].

TABLE H.3. ESTIMATED NUMBER OF PEOPLE EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM AGRICULTURAL NOISE.

Region	Annual L_{dn} (dB)	Area Impacted (sq miles)	Population Density x Area Impacted (persons)	Adjustment Factor*	Adjusted Number of Persons Exposed
Northeast	>65	176	2992	0.064	191
	60-65	383	6511	0.064	417
	55-60	1203	20451	0.064	1309
North Central	>65	1314	9723	0.034	331
	60-65	2862	21179	0.034	720
	55-60	8985	66489	0.034	2261
South	>65	729	5395	0.022	119
	60-65	1587	11744	0.022	258
	55-60	4983	36874	0.022	811
West	>65	284	540	0.008	4
	60-65	619	1176	0.008	9
	55-60	1942	3690	0.008	30
U.S. (Total)	>65	2503	18650		645
	60-65	5451	40610		1404
	55-60	17113	127504		4481

* Obtained by dividing the area impacted above 55 dB (the sum of the 55-60, 60-65, and >65 dB bands) by the total area in each farm region shown in Table H.1, and multiplying by 1.5 to account for the noise from other machinery.

TABLE H.4. U.S. POPULATION EXPOSED TO VARIOUS LEVELS OF L_{dn} OR HIGHER FROM AGRICULTURAL NOISE.

L_{dn} (dB)	Number of People
>65	645
>60	2049
>55	6460

REFERENCES FOR APPENDIX H

H-1 U.S. Department of Commerce, Bureau of the Census, "Statistical Abstract of the United States: 1977," 98th Annual Edition, September 1977.

H-2 U.S. Department of Commerce, Bureau of the Census, "Statistical Abstract of the United States: 1979," 100th Annual Edition, September 1979.

H-3 University of Nebraska - Lincoln, Department of Agricultural Engineering, "Nebraska Tractor Test Data 1977," February 1977.

H-4 Southwest Research Institute, "A Study of Noise Induced Hearing Damage Risk for Operators of Farm and Construction Equipment," U.S. Department of Commerce/National Bureau of Standards, Report No. PB 188-633, December 1969.

H-5 U.S. Department of Commerce, Bureau of the Census, U.S. Department of Agriculture, Economic Research Service, "Farm Population of the United States, 1976," Series Census-ERS, p.27, No. 49, December 1977.

APPENDIX I. BUILDING MECHANICAL EQUIPMENT NOISE EXPOSURE IN THE COMMUNITY AND IN BUILDINGS

I.1 Noise Exposure in Buildings

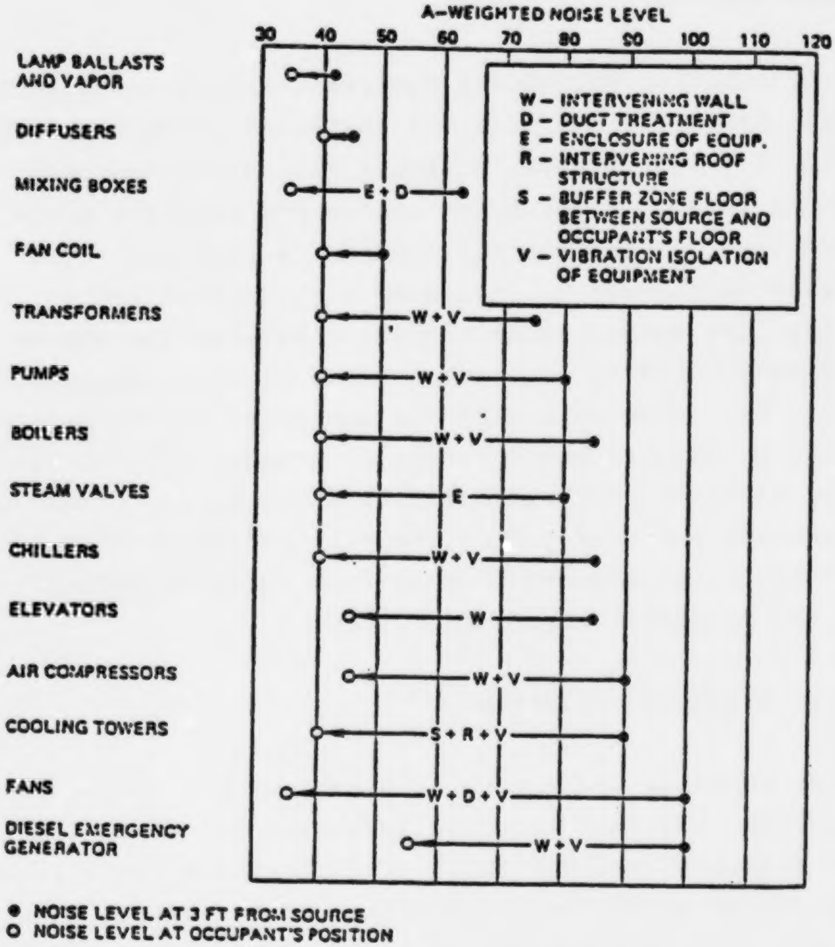
I.1.1 Noise sources

The noise of building mechanical equipment should not normally provide any impact, if designed and installed correctly. The data in ref. I-1 list typical building mechanical equipment and the sound level 3 ft from the source and also the estimated sound level at the nearest occupant's position. The latter figure is derived by including a calculated reduction for the structure and acoustic treatment between the source and the nearest building occupant. These results, included here in Fig. I-1, show that only the emergency diesel generator produces A-weighted sound levels of greater than 45 dB. Since these machines only run intermittently (e.g., 1 hour per week for testing purposes), this analysis indicates that there is relatively little acoustic impact from building mechanical equipment for occupants inside buildings.

I.1.2 Noise exposure estimates

In practice, building mechanical equipment is not always properly installed, and full acoustic treatment is not applied. Experience suggests that the noise of central air conditioning systems, elevator mechanisms, and boiler forced-draft fans commonly produce A-weighted sound levels greater than 45 dB in occupied spaces.

FIG. I.1. RANGE OF BUILDING EQUIPMENT NOISE LEVELS TO WHICH PEOPLE ARE EXPOSED [I-1].



There are many office buildings, hospitals, stores, hotels, and convention centers where the noise of the air conditioning system can be expected to generate similar levels, but any estimate would be speculative at this time.

I.2 Noise Exposure in the Community

I.2.1 Noise sources

The exterior noise produced by building mechanical equipment is most probably dominated by air-moving equipment (fans) located outside the building or located inside the building with a direct unmuffled path to the outside. Examples of such fan-related equipment include air conditioners, boilers, condensers, cooling towers, dehumidifiers, furnaces, humidifiers, and ventilators.

Source level and operating information is available. For example, cooling towers will typically produce A-weighted sound levels of 65 dB at 200 ft when operating at full speed. Axial exhaust fans can produce A-weighted sound levels of 61 dB at 200 ft from the exhaust vent [I-1 to I-4].

I.2.2 Noise exposure estimates

No information is available at this time on the distribution of the population relative to building mechanical equipment to provide a direct estimate of impact. However, it has been observed that building mechanical equipment contributes to the noise environment in built-up areas, and also that community complaints about building mechanical equipment noise are often concerned with nighttime disturbance, when traffic and other noise is minimized. In addition, a poor choice of location, such as one allowing residential buildings to overlook cooling towers, can cause real problems. In a study that considered one such "noisy plan" in a hypothetical apartment unit, noise from building equipment assumed to be on a neighboring roof was the main exterior noise source, producing an L_{dn} of 50 dB inside the unit [I-5]. Next in importance was noise from an adjacent trash chute and elevator system, producing 41 dB inside the unit.

I.3 Concluding Remarks

Building mechanical equipment is probably not a major source of acoustic impacts. However, a noise problem can result from poor design and/or incorrect installation. In this case, the continuous nature of the noise produced can result in very serious local problems. Disturbance to sleep and interference with activities that require concentration probably represent the principal effects. However, insufficient data are presently available to quantify the extent of this problem.

REFERENCES FOR APPENDIX I

I-1 I. Dyer and L. Miller, "Cooling Tower Noise," Noise Control, May 1959.

I-2 ASHRAE Guide and Data Book, 1963, Chapter 14; 1967, Chapter 31; American Society of Heating, Refrigeration and Air Conditioning Engineers Inc., 345 E. 47th Street, New York, NY, 10017.

I-3 G.A. Campano and W.E. Bradley, "Radiation of Noise from Large Natural Draft and Mechanical Draft Cooling Towers," Paper 74-WA/HT-55, presented at ASME Annual Meeting, November 1974.

I-4 J.B. Graham, "Fan Selection and Installation," ASHRAE Symposium Paper June 1975, American Society of Hearing, Refrigeration and Air Conditioning Engineers, Inc., 345 E. 47th Street, New York, NY, 10017.

I-5 R.L. McKay, "Criteria for Interior Residential Noise," BBN Report 3169, for the U.S. Department of Housing and Urban Development, June 1976.

APPENDIX J. HOME APPLIANCE, POWER SHOP TOOL, AND OUTDOOR POWER EQUIPMENT NOISE EXPOSURE IN THE COMMUNITY AND IN BUILDINGS, AND EXPOSURE OF OPERATORS

This section presents noise data and estimates of L_{dn} and $L_{eq}(24)$ for consumer products used in and about the home.

J.1 Noise Sources

The home environment has become increasingly noisy with the advent of powered consumer products designed to aid in the day-to-day tasks of food preparation, personal hygiene, home maintenance, and hobbies. This section will deal with noise from products that fall into three major categories:

- Household Appliances
- Power Shop Tools
- Outdoor Power Equipment.

Other products have been identified as possible contributers to the noise in the home environment but are not included in this section. These are

- Stereos and radios (whose levels are under the control of the user)
- Toys and sporting goods (for which data are lacking at present)
- Heating, ventilation, and air conditioning equipment (see Appendix I)
- Plumbing fixtures (whose levels may be typically low but nonetheless sometimes annoying).

J.2 Noise Exposure Model

The noise level results presented in Table J.1 are taken from a study of consumer product noise [J-1], and these results derive from tests performed on consumer products in accordance with ISO standards for testing of small noise sources. In most cases, the noise levels represent an average of more than one product operated under various normal operating conditions. Since a proper nationwide consumer appliance noise survey has not been performed at this time, the extent to which these averages reflect the actual population of products in use (with their varying degrees of degradation, operating power, and other manufacturer-specific characteristics) is not known.

The measured sound power level (in dB re 10^{-12} watts), along with the average operator distance and the average room acoustical environment allow the calculation of an operator or bystander exposure level. The combination of this exposure level and the estimated yearly usage allow the calculation of a 24 hour L_{eq}. Because there are no data indicating the portion of any product's use during nighttime hours between 2200 and 0700 hours--thereby incurring the 10-dB penalty--the value for L_{eq} (24) will be assumed to be equal to the value of L_{dn}. This assumption may not be too far from reality when one considers that most of these sources are under direct operator control, and common courtesy and normal usage patterns will tend to preclude use during the hours when most people sleep.

Estimates of product ownership come from three different sources. Wherever possible, data from a survey reported in the April 1978 issue of Appliance Manufacturer were used to estimate the percent of households that own a given consumer

TABLE J.1. NOISE FROM CONSUMER PRODUCTS.

Product	Sound Power Level (dB)	Operator Distance (ft)	Room Acoustic Constant	Usage (hrs/wk)	Ownership (%)	Operator Sound Level (dB)	Operator L_{eq} (24)	Population Exposed to L_{dn} >45 (Millions)
Facial Brush	63.5	0.25	35	0.125	3	74.9	43.6	0.0
Hair Clipper	61	0.25	35	0.124	12	72.4	41.1	0.0
Hair Dryer	80	0.25	35	0.985	73	91.4	69.1	53.29
Shaver	70	0.25	35	0.488	42	81.4	56.1	30.66
Tooth Brush	63	0.25	35	0.700	6	74.4	50.6	4.38
Blender	91	3.0	45	0.063	66	90.9	56.6	48.18
Can Opener	69	3.0	45	0.072	79	68.9	35.2	0.0
Coffee Grinder	80	3.0	45	0.019	12	79.9	40.4	0.0
Food Mixer	75	3.0	45	0.187	91	74.9	45.4	66.43
Food Processor	92	3.0	45	0.0125	3	91.9	50.6	2.19
Ice Crusher	82	3.0	45	0.018	6	81.9	42.2	0.0
Juicer	78	3.0	45	0.065	6	77.9	43.8	0.0
Electric Knife	84	3.0	45	0.051	18	93.2	58.7	13.14
Knife Sharpener	84	3.0	45	0.041	12	83.9	47.8	8.76
Dental Irrigator	75	2.0	35	0.166	15	76.3	46.2	10.95
Massager	54	2.0	175	0.0064	6	50.3	6.1	0.0
Pencil Sharpener	79	3.0	175	0.146	6	74.0	43.4	0.0
Pet Clipper	62	1.0	45	0.0064	1	61.9	17.7	0.0
Electric Scissors	74	3.0	175	2.06	15	69.0	49.9	10.95
Sewing Machine	81	3.0	175	1.28	84	76.0	54.8	61.32
Shoe Polisher	75	3.0	175	0.125	3	70.0	38.7	0.0
Floor Polisher	74	6.0	45	0.077	1	73.6	40.2	0.0
Rug Shampooer	94	6.0	175	0.077	47	88.0	54.6	34.31
Vacuum Cleaner	91	6.0	175	1.309	95	85.0	63.9	69.35
Clothes Dryer	73	10.0	45	5.8	58	72.5	57.9	42.34
Clothes Washer	75	10.0	45	3.95	72	74.5	58.2	52.56
Dehumidifier	61	10.0	45	12.95	18	60.5	49.4	39.4
Dishwasher	67	10.0	45	3.435	48	66.5	49.6	35.04
Food Waste Disp.	82	3.0	45	0.351	40	81.9	55.1	29.2
Range Hood	68	3.0	45	1.744	43	67.9	48.1	31.39
Refrigerator	54	10.0	45	42.0	94	53.5	47.5	68.62
Room Air Cond.	67.6	10.0	175	8.318	36	61.3	48.3	78.9
Trash Compactor	74	10.0	45	0.25	4	73.5	45.3	2.92
Air Heater	57	10.0	175	0.208	6	50.7	21.7	0
Fan	70	10.0	175	16.408	54	63.7	53.6	118.3
Humidifier	58	10.0	175	71.09	21	51.7	48.0	46.0
Ice Cream Machine	75	10.0	45	0.058	1	74.5	39.9	0
Movie Projector	69	10.0	175	0.02	6	62.7	23.5	0
Slide Projector	66	10.0	175	0.067	40	59.7	25.7	0
Band Saw	90.5	3.0	45	0.2	1	90.4	61.2	0.73
Belt Sander	102	3.0	45	0.047	12	101.9	66.4	8.76
Bench Grinder	84	3.0	45	0.143	9	83.9	53.2	6.75
Circular Saw	103	3.0	45	0.144	21	102.9	72.2	15.33
Disk Sander	100	3.0	45	0.027	6	99.9	62.0	4.38
Drill Bit Sharp.	88	3.0	45	0.0064	3	87.9	43.7	0

TABLE J.1. NOISE FROM CONSUMER PRODUCTS (CONTINUED).

Product	Sound Power Level (dB)	Operator Distance (ft)	Room Acoustic Constant	Usage (hrs/wk)	Ownership (%)	Operator Sound Level (dB)	Operator L_{eq} (24)	Population Exposed to L_{dn} >45 (Millions)
Electric Drill	93	3.0	45	0.229	66	92.9	64.2	48.18
Multipurpose Drill	102	3.0	45	0.2	3	101.9	72.7	2.19
Engraving Pen	85	3.0	45	0.009	6	84.9	42.2	0
Jointer/Planer	101	3.0	45	0.16	6	100.9	70.7	4.38
Lathe	89	3.0	45	0.16	3	88.9	58.7	2.19
Orbital Sender	94	3.0	45	0.095	12	93.9	61.4	8.76
Radial Arm Saw	102	3.0	45	0.263	9	101.9	73.8	6.57
Reciprocating Saw	98	3.0	45	0.093	12	97.9	65.3	8.76
Rotary Grinder	105	3.0	45	0.01	3	104.9	62.6	2.19
Router	97	3.0	45	0.029	6	96.9	59.3	4.38
Table Saw	104	3.0	45	0.2-8	3	103.9	76.2	2.19
Air Compressor	92	10.0	45	0.10	3	91.5	59.3	2.19
Hedge Trimmer	91	3	$2x10^4$	0.1	9	80.5	48.2	6.57
Chain Saw	115	3	$2x10^4$	0.3	9	109	81.5	6.57
Garden Tractor	105	3	$2x10^4$	0.74	6	94.5	70.9	4.38
Riding Mower	101	3	$2x10^4$	0.74	9	90.5	66.9	6.57
Walkling Mower	100	6	$2x10^4$	0.74	39	83.4	59.9	28.47
Lawn Thatcher	96	6	$2x10^4$	0.04	1	79.4	43.2	0
Leaf Blower	94	6	$2x10^4$	0.1	1	77.4	45.2	0.73
Rotary Tiller	96	6	$2x10^4$	0.1	1	79.4	47.2	0.73
Shredder	97	6	$2x10^4$	0.1	3	80.4	48.2	0.73
Snow Thrower	107	6	$2x10^4$	0.366	12	90.4	63.8	8.76
Lawn Vacuum	109	6	$2x10^4$	0.1	1	92.4	60.2	0.73
Weed Cutter	86	6	$2x10^4$	0.75	12	69.4	45.9	8.76

product [J-2]. Where no data existed, data from a 1980 survey specifically tailored to obtain noise exposure information were used [J-1]. A third study published in the March 1977 issue of Merchandizing was used for comparison [J-3]. The values obtained for each of these surveys differ somewhat due to differences in sample population, sample size, survey date, and survey methodology, but they represent best estimates at the present time.

Usage estimates are also not known with a high degree of accuracy, in light of the extremely varied situations and patterns of usage of individual products in different regions of the country.

For the purpose of this analysis, there are assumed to be two bystanders for products requiring an operator, three for products requiring no operator, and six for products used outside. Based on 1978 Statistical Abstract data, there are approximately 73 million households in the United States.

J.3 Noise Exposure Estimates

As is apparent from reviewing the results shown in Table J.1, a large number of products produce L_{dn} levels in excess of the 45-dB criterion level. However, since these products do not generate levels of sufficient intensity to have an impact on people other than the operator, the number of exposed people is the number of product owners. For certain indoor products without operators (humidifiers, dehumidifiers, fans, and air conditioners), the number of exposed people is based on three people exposed per household. It is also interesting to note that some power shop tools produce levels sufficient to exceed the L_{eq} (24) level of 70 dB for the operator exposure.

These results indicate that a significant noise exposure can occur in the typical home environment particularly if one is engaged in a hobby that uses a product that produces high noise levels. These exposures, while not necessarily harmful in themselves, can be significant for that portion of the population already exposed to the maximum daily noise dose in the workplace. The lack of more precise data on the number of product users and use durations precludes an accurate estimate of nationwide exposure to home products at this time.

REFERENCES FOR APPENDIX J

J-1 "Consumer Product Noise," BBN Report No. 4341 (Draft Final), March 1980.

J-2 Appliance Manufacturers, April 1978.

J-3 Merchandizing, March 1977.

APPENDIX K. OCCUPATIONAL NOISE EXPOSURE OF WORKERS

The U.S. Environmental Protection Agency (EPA) has recommended an equivalent sound level for eight hours [L_{eq} (8 hr)] of 75 dB as the exposure level to protect workers from permanent hearing loss [K.1]. Many workers in agriculture, mining, construction, manufacturing, transportation, and the military are routinely exposed to levels in excess of this recommendation. The legal limits imposed by the Occupational Safety and Health Administration (OSHA) [K.2,K.3], the Mining Health and Safety Administration (MSHA) [K.4], and the Department of Defense (DOD) [K.5] are less restrictive than the EPA-recommended level.

No concrete estimates exist of the number of workers exposed to noise levels greater than an L_{eq} (8 hr) of 75 dB. There is, however, a limited amount of published information on the occupational noise exposure of workers in some occupational categories in selected industries. Even though these data were developed for different purposes, it has been possible to develop estimates of the minimum number of workers exposed to levels greater than an L_{eq} (8 hr) of 85 dB through the use of extensive extrapolations. These estimates are presented in the sections that follow. Brief explanations of the extrapolation techniques and the source data are also presented in the following sections.

In addition to their exposure to continuous noise, many workers are exposed to impact/impulsive noise. This type of noise can greatly increase the amount of hearing loss due to either continuous or impact noise. Recommendations for criteria for exposure to impact/impulsive noise alone and together with high-level continuous noise are under development. Preliminary estimates indicate that 1 million to 4 million workers are routinely exposed to high levels of impact/impulsive noise. Additional details are presented later in this appendix.

As is the case with any estimate, the estimates in this appendix are somewhat limited. The principal difficulty in estimating the occupational noise exposure of the total U.S. work force is in obtaining noise exposure data for a representative population for each of the employment categories and industries analyzed. *The current assessment was restricted to available data and no additional sampling or measurements were included. It should be noted that the available data are often lacking the representativeness of an industry-wide assessment.*

K.1 Noise Exposure in the Agriculture Industry

A number of studies confirm that agricultural workers who operate tractors and other mechanized farm equipment are exposed to A-weighted sound levels greater than 85 dB and that the duration of the noise is sufficiently long that NIPTS may result [K.6, K.7, K.8, K.9, K.10, K.11]. The most complete set of noise exposure measurements was made in 1977 for a group of farm workers on six farms in Nebraska [K.12]. Each worker was fitted with a noise dosimeter for each day worked. During the course of one year, 67 employees worked the equivalent of 13,000 days. From these data, it was possible to estimate the average noise exposure of each worker for the year.

To develop an estimate of the noise exposure of all the agricultural workers from these data, two facts must be considered. First, the noise emitted by farm tractors has been reduced in recent years [K.8, K.9]. The manufacturers of the tractors used on the Nebraska study farms have reduced the noise of their tractors during the past few years by an average of 2 dB. Accordingly, if the Nebraska farm survey were done today, the workers operating those tractors would be exposed to less noise. This effect has been estimated by reducing the noise exposures of each of the 67 workers by 2 dB and recalculating their noise exposure. Table K.1 summarizes the Daily Noise Dose (DND) for each of the workers, what the dose would be if the noise were 2 dB quieter, and the corresponding range of noise levels.

Second, the six farms in this study seem to be more mechanized than "typical" farms. Without any information to relate the mechanization of each of these farms to a typical farm, it is not possible to develop an estimate of the noise exposures for all agricultural workers. An educated guess is necessary: For every situation where workers are exposed as reported in this study, an equal number of workers on other farms have exposures less than 70 dB. Table K.2 summarizes the exposures from Table K.1, adds in the equal number of workers exposed to levels less than 70 dB and presents the percentage for each range.

TABLE K.1. NEBRASKA FARM WORKER EXPOSURE DATA [K.1]

Farm	OSHA DND %	OSHA DND if Equipment 2 dB Quieter %	Range of Noise Level If Equipment 2 dB Quieter dB
#1	93	58	85-90
	38	24	75-80
	61	38	80-85
	18	11	70-75
	3	2	<70
	142	90	90-95
	71	45	80-85
	33	21	75-80
	8	5	<70
	120	76	85-90
	6	4	<70
	97	61	85-90
	18	11	70-75
	0	0	<70
	0	0	<70
	0	0	<70
	5	3	<70
	40	25	80-85
	10	6	<70
	6	4	<70
	8	5	<70
	117	74	85-90
	105	66	85-90
	4	3	<70
	5	3	<70
	55	35	80-85
	162	102	90-95
	178	112	90-95
	97	61	85-90
	72	45	80-85
	52	33	80-85
	115	73	85-90
	38	24	75-80
	4	3	<70
	11	7	70-75
	29	18	75-80
	6	4	<70
	41	26	80-85
	10	6	<70
#2	53	33	80-85
	24	15	75-80
	13	8	70-75
	33	20	75-80
	288	181	90-95
	60	38	80-85
#3	27	17	75-80
	1	1	<70
	14	9	70-75
	27	17	75-80
	1	1	<70
	1	1	<70
	7	4	<70
	7	4	<70
	9	6	<70
	21	13	75-80
	13	8	70-75
#4	7	4	<70
	17	11	70-75
	26	16	75-80
	7	4	<70
#5	83	52	85-90
	35	22	75-80
#6	27	17	75-80
	13	8	70-75
	3	2	<70
	3	2	<70
	3	2	<70

TABLE K.2.
DEVELOPMENT OF EXPOSURE ESTIMATES FOR AGRICULTURAL WORKERS

Range of Sound Level in dB	Number of Workers	Equal Number Exposed to Less Than 70 dB	Totals	%
<70	26	67	93	69.3
70-75	8		8	6.0
75-80	12		12	9.0
80-85	9		9	6.7
85-90	8		8	6.0
90-95	4		4	3.0
Totals	67	67	134	100

Approximately 3.6 million workers are employed in agriculture [K.13]. The percentages in Table K.2 have been used to develop estimates of the noise exposures of agricultural workers. These estimates are presented in Table K.3. Of the 3.6 million agricultural workers, about 323,000 are exposed to an L_{eq} (8 hr) of 85 dB or greater.

TABLE K.3. NOISE EXPOSURE OF AGRICULTURAL WORKERS.

L_{eq} (8 hr) (dB)	Number of Workers (thousands)
90 — 94	108
85 — 89	215
80 — 84	240
75 — 79	323
<75	2701

K.2 Noise Exposure in the Mining Industry

The mining industry consists of the extraction of coal, metals, nonmetallic minerals, and oil and gas from the earth and the preparation of these materials. Noise exposure data in this industry are extremely limited. No noise exposure data are available for the preparation of the mined materials. Data are available for the underground and surface mining of coal. The estimates in this section are based on extrapolations from the mining of coal.

Where the data permit, the L_{eq} (8 hr) exposures have been calculated and will be presented. Data examined were limited to workers exposed to daily noise levels in excess of that allowed by noise exposure regulations of the Federal Coal Mine Health and Safety Act of 1969. However, most of these data are reported as L_{MSHA} values, which are based on a 5-dB doubling rule rather than the 3-dB doubling rule used in deriving an L_{eq} measure. If the sound exposures are continuous at a constant level, both the L_{eq} and L_{MSHA} values would be equal. However, industrial sounds vary considerably, and with a varying sound level, the value of L_{eq} will be greater than the value of L_{MSHA}. Thus, the reported numbers of workers exposed to values of L_{MSHA} are less than would have been reported if L_{eq} calculated exposures had been utilized. For these reasons--lack of data generally available on noise exposures in the mining industry and the units in which the mining exposures were reported--the estimates presented in this section should be regarded as preliminary and probably representative of the minimum number of workers exposed.

Coal Mining

Underground

Data are available from MSHA on the noise exposure of underground coal miners [K.14], based upon the results of a survey of 2632 production workers in 12 underground coal mines. The exposure estimates in this report were developed from specific sound level and operating duration measurements for the equipment commonly encountered, rather than from individually measured worker exposures. Table K.4 presents the reported percent of workers exposed to different ranges of noise exposure. Estimates of the number of workers in underground mining exposed to noise were then developed by multiplying the percentages shown in Table K.4 by the 169,585 miners who worked in deep coal mines in 1979 [K.15]. The first row of Table K.7 (which appears later in this appendix) presents these estimates.

TABLE K.4 NOISE EXPOSURE FOR UNDERGROUND COAL MINE WORKERS.

L_{MSHA}* dB	Percent of Workers Exposed† %
≥90	7.2
85 - 89	14.7
<85**	78.1

* Uses a 5-dB doubling rate.
† In view of the material in Ref. K.16, these estimates appear low.
**Exact lower limits below 85 dB are not precisely known.

Surface

The noise exposure estimates for workers in surface coal mines were developed using the results of a noise exposure survey of operators of mobile machines [K.17]. The related report presented the number of workers with exposures greater than 85 dB and 90 dB and the total number in the survey. The number and percentage of workers exposed to various equivalent sound levels is presented in Table K.5. An estimate of the number of surface miners exposed to the ranges of equivalent sound levels shown in Table K.5 was developed by multiplying the percentages shown in Table K.5 by the number of workers in surface mines--82,147 [K.15]. These figures are presented later in this Appendix in the second row of Table K.7.

TABLE K.5. NOISE EXPOSURE FOR SURFACE COAL MINERS.

L_{MSHA}* dB	Number of Coal Miners†	Percent of Coal Miners (%)
>90	25,225	44.9
85 - 89	12,038	21.4
<85**	18,963	33.7

* Uses a 5-dB doubling rate.
† See Ref. K.17.
**Exact lower limits below 85 dB are not precisely known.

Metal and nonmetallic mineral mines

Underground

As with coal mining, the noise exposures for underground operations in metal and nonmetallic mineral mines are different from those for surface mining. No studies are available identifying the specific noise exposures of workers in this type of mining. However, an estimate has been developed of the percentage of workers in such underground mines who are exposed to varying noise level ranges through the use of information in Ref. K.18. The related report reviews the contribution of noise from diesel-powered underground mining equipment in the extraction of molybdenum, uranium, potash, iron, coal, and salt. The report presents information on diesel equipment sound levels, equipment population, and typical duty cycles.

With this information an estimate can be made of the number of noise exposed workers and their equivalent sound level exposures. Table K.6 presents the estimated exposures. In 1974, 37,000 workers were employed in underground metal and nonmetallic mineral mines [K.18] (or an estimated 24.3% of total underground mines.) An estimate of the total number of underground miners in this part of the industry was developed by applying the distribution from Table K.6 to 24.3% of the 173,800 people who currently work underground in this industry [K.19]. The third row of Table K.7 presents these estimates. Other sources, such as rock drills, fans, and crushers, also generate high levels of noise and were not included in Ref. K-18. Thus, this estimate should be viewed as the minimum number of workers so exposed.

TABLE K.6. NOISE EXPOSURE FOR UNDERGROUND MINERS IN METAL AND NONMETALLIC MINERAL MINES.

L_{eq} (8 hr) (dB)	Percent of Workers (%)
$\geq$90	17.6
85 – 89	11.1
<85	71.3

Surface

About 75.7% (131,567 workers) of the people employed by the metal and nonmetallic mines work above ground (developed from

K.18 and K.20 and the previous section). No information is available on the noise exposure of these workers. The surface mining of metal and nonmetallic minerals is different from surface coal mining. The differences are:

- A higher concentration of equipment exists in metal than in coal
- Drills are percussive in metal and rotary in coal
- More blasting occurs in metal than in coal
- Other unidentified surface equipment may add to noise exposure.

Most of these differences seem to increase the noise exposures of the workers. However, as stated above, no data substantiate this statement. Without any other data, the noise exposure for surface workers in metal and nonmetallic mineral mines has been developed by using the percentages from surface coal (see Table K.5). These estimates are presented in the fourth row of Table K.7.

Oil and Gas Mining

There were 327,500 production workers in oil and gas extraction in 1979 [K.19]. No information on noise exposure of these workers is available. Noise sources are likely to be engines, compressors, and mobile equipment. Without any better information, the percentage distribution data from the last column in Table K.5 for surface coal mine operations were used to develop estimates for this industry. The results are shown in Table K.7.

Summary

Table K.7 presents the noise exposure of the workers in the mining industry: Almost 400,000 workers have noise exposures that exceed 85 dB out of a total employment of 957,000 [K.19].

TABLE K.7. NOISE EXPOSURE IN THE MINING INDUSTRY.

	Noise Level (dB)			Total
	<85	85 – 90	>90	
Underground Coal*	132,446	24,929	12,210	169,585**
Surface Coal*	27,684	17,579	36,884	82,147**
Underground Metal and Nonmetallic†	30,112	4,688	7,433	42,233††
Surface Metal and Nonmetallic*	52,495	25,524	53,548	131,567††
Oil and Gas*	110,368	70,085	147,047	327,500††
Totals for Mining	353,105	142,805	257,122	

*Noise Level is L_{MSHA}.

†Noise Level is L_{eq} (8 hr).

**See Ref. K.15.

††See Ref. K.20.

K.3 Noise Exposure in the Construction Industry

A number of studies confirm that workers in the construction industry are exposed to high levels of noise [K.11, K.21]. A recent British study [K.22] presented values of L_{eq} (8 hr) for machine operators of construction equipment. Table K.8 summarizes these data. By assuming that these exposures are similar to those in U.S. industry, an estimate of the number of construction workers whose exposure exceeds an L_{eq} (8 hr) of 85 dB can be developed. Reference K.23 presents the number of workers in the construction industry by occupation. Accordingly Table K.9 was developed presenting the percentage of workers in the construction industry who work with the specific machine types listed in Table K.8. Unfortunately, Reference K.23 does not provide the number of operators for several of the machine types. Nevertheless, from Table K.9, at least 5.48% of the construction workers appear to operate machines where the L_{eq} (8 hr) exceeds 85 dB. In addition to the machine operators, construction laborers are also exposed to noise. About 11.35% of the construction work force are laborers [K.23]. The laborer category includes workers who are exposed to high levels of noise, such as from jack hammers and other air- operated tools, as well as individuals with less noise exposure [K.24]. However, no definitive estimates are available for noise exposure of the laborers.

Without a definitive breakdown of the number of workers in each of the laborer categories, the number of laborers who operate the noisy equipment types cannot be determined. A review of the list of jobs performed by laborers suggests that many of these workers could be exposed to high levels of noise. Without better information, it is estimated that 50% of the laborers are exposed to levels greater than an L_{eq}

TABLE K.8. NOISE EXPOSURE OF CONSTRUCTION MACHINERY OPERATORS.*

Equivalent Sound Level L_{eq} (8 hr) (dB)	Machine Types
105 — 109	Pneumatic breakers
100 — 104	Pavers
95 — 99	Scrapers Dumpers Bar benders Hydraulic breakers Pile drivers (diesel & pneumatic)
90 — 94	Dozers Excavators Cranes Front loaders Rollers Poker vibrators
85 — 84	Backhoes Saws
80 — 84	Concrete pumps Pile drivers (gravity bored)
75 — 79	Graders Concrete mixers Trucks Pumps Generator Compressors

*Developed from Ref. K.22.

TABLE K.9. PERCENTAGE OF CONSTRUCTION MACHINERY OPERATORS BY MACHINE TYPE* AND NOISE LEVEL.†

L_{eq} (8 hr) (dB)	Machine Types	Percent of Construction Workers Operating Machine Type (%)
$\geq$85	Dozers	0.99
	Excavators (include pavers, scrapers, hydraulic breakers, pile drivers, front loaders, back hoes, rollers, poker vibrators)	3.85
	Saws	0.04
	Cranes	0.60
	Pneumatic breakers	**
	Dumpers	**
	Bar benders	**
Total		5.48

*See Ref. K.23.

†See Ref. K.22.

**Not listed separately.

(8 hr) of 85 dB. Since about 11.35% of the construction force are laborers [K.23], a total of 11.16% [5.48 + 0.5 (11.35)] could be exposed to levels greater than an L_{eq} (8 hr) of 85 dB. Since there are other jobs in the construction industry that may be noisy and for which there is no definitive information, this estimate is more likely an estimate of the minimum number exposed to these levels than an estimate of the maximum number.

Total employment in the construction industry for 1979 was about 4.6 million people [K.19]; thus, about 513,000 workers are estimated to be exposed to levels greater than an L_{eq} (8 hr) of 85 dB.

K.4 Noise Exposure in the Manufacturing and Utility Industries

Estimates of noise exposures of workers in the manufacturing and utility industries are presented in this section. The high noise level industries of interest are listed in Table K.10 along with the number of production workers in each industry. In addition to these industries, some exposure to high level noise may occur in the instrument manufacturing (SIC 38) and the miscellaneous manufacturing (SIC 39) industries. All of these estimates are derived from the recently available OSHA information [K.25, K.26].

Table K.11 presents the total estimated noise exposure for workers in these industries [K.19]. Since L_{eq} (8 hr) is equal to L_{OSHA} only when the noise exposure is constant and since the noise levels in the industrial work place fluctuate over a considerable range, these estimates should be viewed as minimum estimates of the number of workers at an L_{eq} of the same value. Nevertheless, more than 5.1 million

TABLE K.10. INDUSTRIES INCLUDED IN ANALYSIS.

Industry	SIC Code	Number of Production Workers (thousands)
Food	20	1,176.2
Tobacco	21	52.5
Textiles	22	777.0
Apparel	23	1,122.2
Lumber and Wood	24	646.3
Furniture and Fixtures	25	398.0
Paper	26	541.5
Printing and Publishing	27	702.2
Chemicals	28	636.9
Petroleum and Coal	29	139.7
Rubber and Plastics	30	601.1
Leather	31	207.4
Stone, Clay, and Glass	32	560.5
Primary Metals	33	978.3
Fabricated Metals	34	1,305.9
Machinery Except Elec.	35	1,616.2
Electric Machinery	36	1,378.6
Transportation Equipment	37	1,404.2
Utilities	49	659.3
Total		14,904.0

*See Ref. K.19.

TABLE K.11. NOISE EXPOSURE OF WORKERS IN MANUFACTURING AND UTILITY INDUSTRIES.*

Exposure Level (dB)	Percent Exposed† (%)	Number Exposed**
>100	2.87	427,745
95 — 99	5.47	815,249
90 — 94	10.98	1,636,459
85 — 89	15.06	2,244,542
80 — 84	18.74	2,793,010
<80	46.88	6,986,995
Total	100.00	14,904,000

*Includes SIC Codes 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, and 49. SIC's 38 and 39 of the manufacturing sector are not included. Only SIC 49 of Transportation and Public Utilities is included in this table.

†See Ref. K.25.

**Based on a total population of 14,904,000 [*K.19*] workers in these industries are exposed to levels in excess of an L_{eq} (8 hr) of 85 dB.

K.5 Noise Exposure in the Transportation Industry

This section presents estimates of the occupational exposure to noise of operators of commercial aircraft, trucks, buses, rail locomotives, and rapid transit cars. Even less data are available for these operators than are available in other industries. However, preliminary estimates have been developed based on extrapolations from the available data. In general, average noise levels at either the operator position or in a location not too far from the operator position are available [K.27, K.28, K.29, K.30, K.31, K.32, K.33, K.34, K.35, K.36, K.37]. Data for the number of operators were available for some modes of transportation but had to be developed for other modes [K.38, K.39, K.40, K.41, K.42, K.43]. The average duration of exposure was estimated for each of the operators [K.40, K.45, K.46]. The L_{eq} (8 hr) was derived from the average sound level, the estimated number of hours of annual exposure, and a total of 1880 hr in a year.

Table K.12 summarizes the estimates of the A-weighted sound level, the annual exposure, the L_{eq} (8 hr), and the population exposed. The operators with exposures greater than an L_{eq} (8 hr) of 85 dB are the truck drivers and the motormen and conductors on rapid transit systems. Surprisingly, the personnel in the locomotive cabs do not appear to be exposed to levels greater than an L_{eq} (8 hr) of 85 dB. In total, about 1.934 million operators are exposed to levels greater than L_{eq} (8 hr) of 85 dB.

TABLE K.12. TRANSPORTATION OCCUPATIONAL NOISE EXPOSURE ESTIMATES

Source	Estimated A-Weighted Sound Level at Operator Position (dB)	Annual Exposure (Hr)	Estimated L_{eq} (8 hr) (dB)	Population Exposed
Aircraft				
[K.27,K.38,K.44,K.45,K.46]				
Commercial* Jet				
Cockpit Crew	80†	900[K.44,K.46]	77	36,987[K.38]
Flight Attendants	85[K.27]	1260[K.45]	83	52,566[K.38]
Commercial* Propeller				
Cockpit Crew	95**	900[K.44,K.46]	92	90††
Flight Attendants	94[K.27]	1260[K.45]	92	128††
Trucks (Medium and Heavy)				
[K.28,K.29,K.30,K.39]	90[K.30]	1410§	89	1,923,000[K.39]
Buses				
[K.27,K.31,K.40]				
City (commuter bus)	79[K.27]	1880[K.40]	79	143,000[K.40]
Intercity	74[K.31]	1770[K.40]	74	24,000[K.40]
School	84[K.31]	440[K.40]	78	442,000[K.40]
Railroads				
[K.32,K.33,K.34,K.35,K.41 K.42]				
Locomotives	78[K.32]	1880	78	75,000[K.41]
Rapid Transit				
[K.27,K.36,K.37,K.43]				
Motormen and Conductors	86[K.27]	1970	86	11,083[K.43]

*Certificated route air carriers only.

†Estimated from Ref. K.27. Pilots in jet aircraft are farther from the engines, estimate 5 dB less noise in cockpit.

**Estimated from Ref. K.27. Pilots are closer to noise source.

††Estimated from number of aircraft in Ref. K.38.

§The average work week in the transportation industry is 30.7 hours [K.39]. Estimate that drivers spend 75% of time in truck.

K.6 Noise Exposure in the Department of Defense

Air Force

Of the 807,000 military (567,000) and civilian (240,000) employees of the U.S. Air Force in 1980 [K.39], 134,200 were given annual audiograms in 1980 and are presumably exposed to levels in excess of 85 dB [K.47]. The details are as follows:

Classification	Number of Air Force Personnel Receiving Audiograms in 1980
Military personnel	106,500
Civilian personnel	27,700
Total	134,200

Army

The Army included 1,107,000 military (757,000) and civilian (350,000) employees in 1978 [K.39]. Measured noise exposures for these personnel are unavailable at this time. Preliminary figures suggest that about 500,000 personnel (400,000 military and 100,000 civilians) are routinely exposed to high sound levels in excess of 85 dB [K.48].

Navy

In 1978, the Navy included 1,028,000 military (717,000) and civilian (311,000) employees [K.39]. Unfortunately, direct estimates of the noise exposure of Navy personnel are unavailable [K.49]. Assuming that Navy personnel are exposed to noise sources similar to those in the Army and Air Force, a preliminary estimate can be developed. The weighted average percentage of military personnel in the Army and Air Force exposed to levels greater than an L_{eq} (8 hr) of 85 is (400,000 + 106,500)/(757,000 + 567,000) or 38.3%. The weighted average percentage of civilian personnel in the Army and Air Force exposed to levels greater than an L_{eq} (8 hr) of 85 is (100,000 + 27,700)/(350,000 + 240,000) or 21.6%. Using these percentage values for the Navy results in the following estimates:

Military	.383 x 717,000 = 274,611
Civilian	.216 x 311,000 = 67,176.

Table K.13 summarizes the exposure of DOD personnel--about 976,000 personnel have estimated exposures greater than an L_{eq} (8 hr) of 85 dB.

Other

In addition, 77,000 non-military employees of DOD are in positions where occupational noise exposure cannot be assessed [K.39].

K.7 Exposure to Impact/Impulsive Noise

Two studies present estimates of the number of workers exposed to impulsive type noise. One study, a walk-through survey of 25 establishments estimates that 2,665,687 workers are exposed to impulsive noise [K.50]. The level and number of impulses were not reported. The second study [K.51] identifies several hundred sources of impulsive noise for a wide range of industries. This study estimates that 1,200,000 workers are directly impacted by impulsive noise and that 3,430,000 workers are indirectly impacted. The peak sound pressure levels ranged from 85 to 147 dB with most of the levels greater than 115 dB. However, no measure of the number of impulses per day per worker were developed. In addition to these workers, both civilian and military personnel are likely to be exposed to impulse noise, particularly gunfire and the manufacturing type of operations used to refurbish military vehicles, ships, and aircraft.

TABLE K.13. ESTIMATED OCCUPATIONAL NOISE EXPOSURE OF DEPARTMENT OF DEFENSE PERSONNEL.

Service	Total Military Population* (thousands)	Military at Levels ≥85 dB (thousands)	Total Civilian Population* (thousands)	Civilian at Levels ≥85 dB (thousands)	Total Personnel* (thousands)	Total at Levels ≥85 dB (thousands)
Army	757	400.0	350	100.0	1107	500.0
Air Force	567	106.5	240	27.7	807	134.2
Navy	717	274.6	311	67.2	1028	341.8
Other	---	---	---	---	77	0.0
Total	2041	781.1	901	194.9	3019	976

*See Ref. K.39.

The figures from these two studies suggest that a minimum of 1.2 to 4.6 million workers are exposed to impulsive noise.

K.8 Summary of Worker Noise Exposure Estimates

Table K.14 summarizes the exposure estimates developed in the preceding sections.

TABLE K.14 SUMMARY OF U.S. POPULATION EXPOSED TO L_{eq} (8 hr) LEVELS OF 85 dB OR HIGHER FROM OCCUPATIONAL SOURCES

Employment Area	Total Employment (thousands)	Total Number of People Exposed to Greater Than an L_{eq} (8 hr) of 85 dB (thousands)
Agriculture	3,600 [*K.13*]	323
Mining	957 [*K.19*]	400
Construction	4,644 [*K.19*]	513
Manufacturing and Utility Industrial	21,781 [*K.19*]	5,124
Transportation	4,345 [*K.19*]	1,934
Military (DOD)	3,019 [*K.39*]	976
Total of These Areas	38,346	9,270

On the basis of the figures in Table K.14 it is estimated that at least 24% of the total number of employees in the industrial, agricultural, transportation and military sectors are exposed to levels greater than an L_{eq} (8 hr) of 85 dB.

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APPENDIX L. TRANSPORTATION NOISE EXPOSURE OF OPERATORS AND PASSENGERS

L.1 Noise Exposure Model

The analysis of the noise impact on operators and passengers of transportation vehicles in nonoccupational situations is based on

- Average noise levels at the operator/passenger positions during an in-use duty cycle

- Number of people exposed in the United States

- Average duration of their annual exposure.

The annual L_{eq} (24) for each type of equipment is derived from the average sound level at the operator/passenger's position on the basis of the estimated average annual exposure in hours for that type of equipment.

The following transportation noise sources are assessed:

- Aircraft
- Automobiles
- Trucks
- Buses
- Motorcycles
- Rail Locomotives and Cars
- Rapid Transit Cars.

L.2 Noise Emission Levels

Noise source levels at the position of operators and passengers have been taken from a number of sources, including the EPA report on "Passenger Noise Environments of Enclosed Transportation Systems" [L-1].

Noise in transportation vehicles characteristically rises and falls in accordance with the duty cycle of the task at hand. Passengers on city buses are exposed to intermittent noise as the buses make frequent stops to receive or discharge passengers, whereas much of the passenger's trip on intercity buses is spent in the steady-cruise mode, with corresponding steady noise levels. In addition, the trip lengths are different between the two modes. For this study, the average sound level over a characteristic trip was used, especially where intermittency is the chief characteristic of the mode. Only where the trip consists of relatively long periods in cruise conditions are the maximum power sound levels used to represent the source level.

L.3 Population Distribution

The population exposed to noise in transportation vehicles was estimated from a number of sources, including transit ridership statistics, auto registrations, and aircraft enplanement figures. The greatest uncertainty is use factors for privately owned and operated vehicles, for which data on observed driver behavior and personal experience of members of the population being characterized were used.

L.4 Noise Exposure Estimates

Table L.1 presents estimated noise levels at passenger and/or operator locations, annual hours of exposure, and exposed-population data for operators and passengers of transportation noise sources in nonoccupational situations, based on these average estimates. The 24-hour average annual exposure levels [$L_{eq}(24)$] shown in the table are computed from the equation:

$$L_{eq}(24) = L_A + 10 \log (H/8760), \text{ dB}, \qquad (L.1)$$

where L_A is the A-weighted sound exposure level, H is the annual number of hours of exposure, and 8760 are number of hours in a year.

As an example, for commercial jets:

$$\begin{aligned} L_{eq}(24) &= 85 + 10 \log (5/8760) = 85 - 32.4 \\ &= 53 \text{ dB}. \end{aligned} \qquad (L.2)$$

These estimates for the impact of transportation system noise on passengers must be viewed with care. To produce an estimate, it was necessary to use average sound levels and average annual exposures. Especially difficult to estimate, for almost all sources, is the number of "repeat riders." For example, though statistics are often available on "passenger miles" or "total trips" per year, for many modes of transportation almost no data are available that show how many times per year an average passenger uses a particular mode of transportation. Thus, though the data readily yield the total person-hours of exposure per year, the data do not show how many people share this total exposure.

TABLE L.1. TRANSPORTATION NOISE EXPOSURE DATA AND IMPACT ESTIMATES (NONOCCUPATIONAL).

Source	A-weighted Sound Level (dB)	Annual Exposure (hr)	$L_{eq}(24)$ (dB)	Population Exposed (× 10^6)
Aircraft				
Commercial Jet [*L-1,L-3,L-4,L-22*]	85	5	53	81.3
General Aviation [*L-1,L-2,L-23*]	94	100	75	0.37
Helicopters [*L-1,L-22*]	94	20	68	0.06
Automobiles [*L-1,L-5,L-6,L-7,L-18*]	75	313	61	159.0
Motorcycles (On road) [*L-8,L-18,L-19*]	98	150	80	[illegible].2
Trucks (Personal Use) [*L-5,L-9,L-18*]	85	180	68	5.7
Buses				
Intercity [*L-1,L-4,L-10,L-16*]	80	9	50	66.0
Commuter [*L-1,L-10,L-11,L-16, L-21*]	84	500	72	10.4
Railroad				
Commuter Cars [*L-1,L-12,L-16*]	73	159	56	0.5
Rapid Transit (Heavy Rail) [*L-11,L-12,L-13,L-16 L-20*]				
NY City [*L-14,L-15,L-17*]	93	229	77	2.0
Other [*L-2,L-15,L-16*]	85	229	69	0.17

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APPENDIX M. RECREATIONAL NOISE EXPOSURE OF OPERATORS AND PASSENGERS

M.1 Noise Exposure Model

The noise exposure of operators and passengers on recreational vehicles is modeled in a manner identical to that described for transportation vehicles (see Appendix L). The following recreational noise sources are assessed:

- Snowmobiles
- Motorcycles
- Pleasure boats
- Racing cars.

M.2 Noise Emission Levels

Noise source levels of recreational vehicles have been taken from data in the open literature. In many cases, data were available on noise levels at the operator's ear. Auto racing cars were an exception, and the estimates are based on projecting the 50-ft sound level back to the interior of the car.

As in the case of transportation vehicles, the time history of noise exposure is intermittent; it is based on the desired use of the equipment. A distinction can be made, however; the operator of a recreational vehicle has freedom in selection of the duty cycle, whereas the operator/passenger of a transportation vehicle is restricted to a pattern of actions based on the trip definition. As a result, there is a greater inaccuracy in estimating the average noise level during exposure of an operator of a recreational vehicle.

M.3 Noise Exposure Estimates

Table M.1 presents the sound level, annual exposure, and exposed-population data for each of the recreational noise sources. The equivalent 24-hour exposure [$L_{eq}(24)$] is computed from the equation

$$L_{eq}(24) = L_A + 10 \log (H/8760), \text{ dB}, \qquad (M.1)$$

where L_A is the A-weighted sound exposure level, H is the annual number of exposure hours, and 8760 is the number of hours in a year.

As an example, for snowmobiles

$$L_{eq}(24) = 102 + 10 \log (80/8760) = 102 - 20.4 = 82 \text{ dB}. \qquad (M.2)$$

TABLE M.1. RECREATIONAL NOISE EXPOSURE DATA AND IMPACT ESTIMATES.

Source	A-weighted Sound Level (dB)	Annual Exposure (hr)	$L_{eq}(24)$ (dB)	Population Exposed ($\times 10^6$)
SNOWMOBILES [*M-1*,*M-2*, *M-10*]	102	80	82	1.7
MOTORCYCLES [*M-3*,*M-4*, *M-9*] (off-road)	100	80	80	2.6
MOTORBOATS [*M-5*,*M-6*, *M-7*,*M-11*]*				
< 10 hp	88	100	69	11.2
10-50 hp	85	100	66	12.9
> 50 hp	88	100	69	8.9
Inboard/outboard	91	100	72	2.3
Inboard	84	100	65	4.7
AUTO RACING [*M-8*]				
Oval Track Racing	105	104	86	0.04
Drag Racing Not Supercharged	122	1	83	0.08
Drag Racing Supercharged	140	0.4	97	0.01
Sports Car Racing	105	138	87	0†
Tractor Pulls	115	42	92	0.01

* Motorboat source levels based on 50% of time at full throttle, 50% of time at half throttle.

† Less than 5000.

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